

## AN ABSTRACT OF THE THESIS OF

Raymond E. Rainbolt for the degree of Master of Science in Wildlife Science presented on October 9, 1997. Title: Control and Biology of Feral Goats on Aldabra Atoll, Republic of Seychelles.

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Abstract approved: \_\_\_\_\_  
Bruce E. Coblenz

The control of feral goats (Capra hircus) and relevant aspects of their biology were studied on Aldabra Atoll, Republic of Seychelles, from October 1993 - May 1994 and November 1994 - May 1995. A total of 832 goats were killed on Aldabra using both the Judas goat technique and traditional hunting methods; a total of 28 Judas goats were used during the entire campaign. The remnant goat populations on Ile Picard (N = 13) and Ile Malabar (N = 19) were eradicated during the first season. On Grande Terre, a total of 798 (374 M: 424 F) goats were killed. The overall kill rate on Grande Terre was 0.37 goats killed/hour with 1.66 shots fired/goat. A total of 1,042 goats were encountered of which 26.1% escaped. Mean group size was 3.2 with a range of 1 to 20. Judas goat hunting became increasingly important over time with 18.0% (n = 85) of goats killed in the first season being in the presence of Judas goats; 42.3% (n = 126) of goats killed during the second season were in the presence of Judas goats. The overall kill rate for the project was almost 2 times greater for Judas goat hunting (0.61 goats killed/hr) than traditional hunting (0.32 goats killed/hr); Judas goat hunting was approximately 70% more effective than traditional hunting when compared using multiple linear regression. There was a significant relationship between Judas goat home range size and the number of conspecifics killed. Feral goats on Aldabra may be unique among feral goat populations by apparently not responding to population reductions in a density-dependent manner. For the first season, the intrinsic rate of increase (r) was 0.45; r = 0.39 for the second season. Twinning rates were 30.7% and 37.5% in the first and second seasons, respectively. I subjectively estimated

approximately 60-120 goats remaining on all of Grande Terre at the end of the project; 84 goats were estimated using the Leslie-Davis removal method of population estimation.

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Control and Biology of Feral Goats on Aldabra Atoll, Republic of Seychelles

by

Raymond E. Rainbolt

A THESIS

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Master of Science thesis of Raymond E. Rainbolt presented on October 9, 1997

APPROVED:

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Head of Department of Fisheries and Wildlife

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Dean of Graduate School

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Raymond E. Rainbolt, Author

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# **Control and Biology of Feral Goats on Aldabra Atoll, Republic of Seychelles**

## **Chapter 1 INTRODUCTION**

Feral goats (Capra hircus) are a cosmopolitan ecological problem, particularly in insular systems where native biota have evolved in the absence of large mammalian herbivores (Coblentz 1978). Feral goats have seriously affected native vegetation (Furon 1958, Mueller-Dombois and Spatz 1974, Coblentz 1977, Hamann 1979, Cronk 1986) and wildlife (MacFarland et al. 1974, Franklin et al. 1979, Leathwick et al. 1983, Cruz and Cruz 1987) in numerous areas of the world. Feral herbivorous mammals are so destructive that it is virtually impossible to preserve or restore an island ecosystem without their elimination (Vitousek 1988).

Feral goats were first introduced to Aldabra Atoll (9° 24' S, 46° 20' E), Republic of Seychelles, sometime prior to 1878 (Stoddart 1981). Goats were most likely introduced to provide a source of meat for passing seafarers, and for a settlement later established on Ile Picard. In 1900 "several hundred" goats were reported on Ile Picard; by 1906 goats had been introduced to Grande Terre where "hundreds" were reported in 1916 and "thousands" in 1929 (Stoddart 1981). During the Royal Society Expedition in 1967-68, goats were observed on all 4 major islands of the atoll and 1 islet in the lagoon -- Ile Picard, Ile Polymnie, Ile Malabar, Grande Terre, and Ile Espirit, respectively (Stoddart 1971).

With the exception of exotic organisms, Aldabra has remained a relatively pristine ecosystem due to its shortage of freshwater, lack of exploitable resources, inaccessibility, and general inhospitableness. Aldabra has the greatest number of giant tortoises (Geochelone gigantea) in the world with approximately 150,000 individuals (Bourn and Coe 1978). There are 10 endemic subspecies and 2 endemic species of birds, including the rare Aldabran brush warbler (Nesillas aldabranus) which was estimated to number only 13 individuals in 1983 (Hamblen et al. 1985). Of 206 plant

species, 166 are indigenous and 20% are endemic (Renvoize 1971). Aldabra was declared a Special Reserve under the Seychelles National Parks and Nature Conservancy Act in 1981, and a year later was designated a UNESCO World Heritage Site.

The first feral goat population census occurred in 1976-77 when 500-600 individuals were estimated atoll-wide (Gould and Swingland 1980). Concern was expressed that goats would invade the western end of Ile Malabar and alter the remaining habitat of the brush warbler (Prys-Jones 1978, Gould and Swingland 1980). Goats were again censused in 1982 (Newing et al. 1984) and 1985-86 (Burke 1988a) which resulted in population estimates of  $2,560 \pm 560$  and approximately 1,000, respectively. This 2- to 5-fold increase in the goat population in less than a decade prompted greater concern about the impacts feral goats were having on the Aldabra ecosystem. In November 1986 the Seychelles Islands Foundation (SIF) declared that eradication of feral goats by shooting would be the official management policy on Aldabra (Burke 1988b).

There are three main feral goat management strategies (Van Vuren 1992). The first strategy is to simply do nothing. Doing nothing is the least expensive alternative economically, but the most costly ecologically. Having no control program on Aldabra would continue to result in direct damage to the vegetation, and indirectly affect the giant tortoises and other native fauna. The second alternative is to implement a control program to reduce goat densities and ecological damage in localized areas. However, feral goats have the potential to respond to reductions in populations with increased reproductive rates (Rudge and Clark 1978, Coblenz 1982, Parkes 1984). A goat population reduced by 80% could rebound to 90% of the original level in only 4 years (Rudge and Smit 1970). Not only does ecological damage continue, but control programs must continue indefinitely and require a regular expenditure of funds. The third and final strategy is eradication. Although eradication is usually expensive and logistically difficult, only a single long-term effort is required to be successful, and the ecosystem is given the opportunity to recover. Eradication of feral goats is less costly in the long-run both economically and ecologically. This is the case particularly on

Aldabra because of its designation as a World Heritage Site, remoteness, and size and topography which makes eradication a desirable and feasible option.

UNESCO funded a limited control program in January-March 1987 and 1988 to assess the need and potential for eradicating feral goats from Aldabra. This control program concentrated on the goat population on Ile Malabar and the areas of highest goat concentrations on Grande Terre which resulted in the removal of 883 goats -- 61 from Ile Malabar, 8 on Ile Picard, and 814 from Grande Terre (Coblentz et al. 1990). Goats were altering species composition and regeneration of vegetation, as well as reducing forage and shade cover for the giant tortoise and possibly reducing the habitat of the brush warbler (Coblentz and Van Vuren 1987). Coblentz et al. (1990) strongly recommended the removal of the remaining goats on Aldabra and proposed an eradication effort employing the Judas goat technique (Taylor and Katahira 1988).

Shooting is an effective means of controlling feral goats (Daly and Goriup 1987, Van Vuren 1992), but removing the last few goats can be difficult and costly. As control efforts continue and the goat population declines, goats become more wary and increased vegetative cover makes goats less observable. For example, on Isla Marchena, Galápagos, Ecuador, 250 hunter-days were required to kill the last 2 goats (Daly and Goriup 1987); killing the last 5 goats from Raoul Island, New Zealand took 2 hunter-years (Daly and Goriup 1987) at a cost of US\$6,000 per goat (Daly 1989). To assist in the location and shooting of goats, the Judas goat technique was developed which exploits the gregarious nature of goats. Radio transmitters are placed on selected goats (Judas goats), which are released and allowed to seek out conspecifics. The Judas goat is radio-tracked and any conspecifics are shot. The Judas goat technique has been used successfully to eradicate remnant goat populations in Hawaii Volcanoes National Park (Taylor and Katahira 1988) and on San Clemente Island, California (Keegan et al. 1994a). The ability to eradicate an entire feral goat population on an isolated island ecosystem in an effective and cost-efficient manner would have major ramifications in exotic species management. The refinement of the Judas goat technique was the goal of this study. My objectives were (1) to determine the effectiveness and efficiency of the Judas goat technique during a feral goat eradication

campaign; (2) to determine if age or residency of Judas goats can affect efficiency; (3) to determine home range sizes of Judas goats and distances they will travel to locate conspecifics; and (4) to determine if goat productivity responded to a reduction in the population.

## Chapter 2 CONTROL OF FERAL GOATS ON ALDABRA ATOLL, REPUBLIC OF SEYCHELLES

### INTRODUCTION

Feral goats (Capra hircus) are a cosmopolitan ecological problem, particularly in insular systems where native biota have evolved in the absence of large mammalian herbivores (Coblentz 1978). Feral goats have seriously affected native vegetation (Furon 1958, Mueller-Dombois and Spatz 1974, Coblentz 1977, Hamann 1979, Cronk 1986) and wildlife (MacFarland et al. 1974, Franklin et al. 1979, Leathwick et al. 1983, Cruz and Cruz 1987) in numerous areas of the world. Feral herbivorous mammals are so destructive that it is virtually impossible to preserve or restore an island ecosystem without their elimination (Vitousek 1988).

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When control of feral goats is the preferred management alternative, there are two main strategies (Van Vuren 1992). The first alternative is to implement a control program to reduce goat densities and ecological damage in localized areas. However, feral goats have the potential to respond to reductions in populations with increased reproductive rates (Rudge and Clark 1978, Coblentz 1982, Parkes 1984). A goat

population reduced by 80% could rebound to 90% of the original level in only 4 years (Rudge and Smit 1970). Not only does ecological damage continue, but control programs must continue indefinitely and require a regular expenditure of funds. The second strategy is eradication. Although eradication is usually expensive and logistically difficult, only a single long-term effort is required to be successful, and the ecosystem is given the opportunity to recover. In the long-term, eradication of feral goats is less costly both economically and ecologically, particularly on Aldabra because of its ecological value, designation as a World Heritage Site, and remoteness which makes getting there expensive and logistically difficult.

Shooting is an effective means of controlling feral goats (Daly and Goriup 1987, Van Vuren 1992), but removing the last few goats can be difficult and costly. As control efforts continue and the goat population decreases, goats become more wary and increased vegetative cover makes goats less observable. For example, on Isla Marchena, Galápagos, Ecuador, 250 hunter-days were required to kill the last 2 goats (Daly and Goriup 1987); killing the last 5 goats from Raoul Island, New Zealand took 2 hunter-years (Daly and Goriup 1987) at a cost of US\$6,000 per goat (Daly 1989). To assist in the location and shooting of goats, the Judas goat technique was developed which exploits the gregarious nature of goats. Radio transmitters are placed on selected goats (Judas goats), which are released and allowed to seek out conspecifics. The Judas goat is radio-tracked and any conspecifics are shot. The Judas goat technique has been used successfully to eradicate remnant goat populations in Hawaii Volcanoes National Park (HVNP) (Taylor and Katahira 1988) and on San Clemente Island (SCI), California (Keegan et al. 1994a).

Further refinement of the Judas goat technique was the goal of this study. Both in HVNP (Taylor and Katahira 1988) and on SCI (Keegan et al. 1994a), Judas goats were used in the removal of remnant goat populations. It was not known whether using Judas goats during the initial stages of a control campaign would be more efficient than traditional hunting methods, or at what stage of the control operation the Judas goat technique becomes more effective. All Judas goats in HVNP (Taylor and Katahira 1988) and SCI (Keegan et al. 1994a) remained within several kilometers of



their release site, even if they were captured from more distant places. Goats on SCI were all non-residents captured initially on Santa Catalina Island (Keegan et al. 1994a), while at least some of the goats in HVNP were non-residents (Taylor and Katahira 1988). It was not known whether resident Judas goats would be more efficient at finding conspecifics if they were captured and released in the same area (resident goats), or transported to an unfamiliar release site (non-resident goats). The ages of Judas goats were not specified on either HVNP (Taylor and Katahira 1988) or SCI (Keegan et al. 1994a). A young (e.g., 0.5 - 1.5 yrs) Judas goat is more easily transported, and may be more social and likely to move greater distances. If Judas goats increase their travel distances and home range sizes during a control campaign, they may locate more conspecifics and improve efficiency of the control program (i.e., reduce the need to capture new goats, or recapture and relocate Judas goats). The maximum distance a female Judas goat travelled in HVNP was 6.2 km (Taylor and Katahira 1988). On SCI, Judas goats travelled an average of 4.8 km to find conspecifics, and continued to locate other goats even when the population was nearly eradicated (Keegan et al. 1994a).

The ability to eradicate an entire feral goat population on an isolated island ecosystem in an effective and cost-efficient manner would have major ramifications in exotic species management. My objectives were (1) to determine the effectiveness and efficiency of the Judas goat technique during a feral goat eradication campaign; (2) to determine if age or residency of Judas goats can affect efficiency; and (3) to determine home range sizes of Judas goats and distances they will travel to locate conspecifics.

## METHODS

### Study Area

Aldabra Atoll (Figure 1.1) is located in the western Indian Ocean approximately 390 km northwest of Madagascar, 650 km east of the African mainland, and 1,170 km southwest of Mahé, the principal island of the Republic of Seychelles. Aldabra has a total land area of 155 km<sup>2</sup> and consists of four principal islands--Ile Picard (9.3 km<sup>2</sup>),

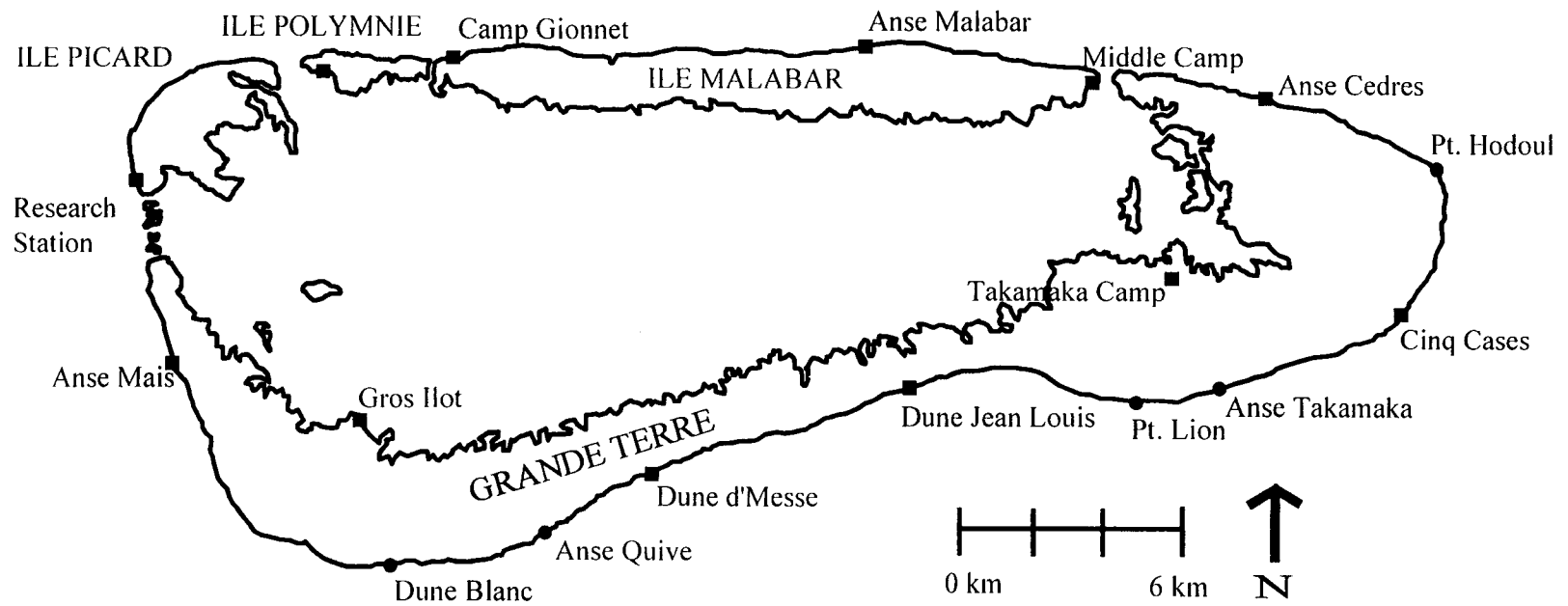


Figure 1.1 Aldabra Atoll, Republic of Seychelles.

Ile Polymnie (1.8 km<sup>2</sup>), Ile Malabar (26.4 km<sup>2</sup>), and Grande Terre (110 km<sup>2</sup>). The atoll is approximately 34 km long, and 14.5 km at the broadest section of its north-south axis. The four islands, averaging 2 km in width, are separated by channels and encircle a large (210 km<sup>2</sup>), shallow tidal lagoon (Stoddart et al. 1971).

The climate of Aldabra is semi-arid and tropical (Farrow 1971). Aldabra experiences two seasons: a "wet" season occurring roughly between December and April when lighter and more variable northwesterly monsoon winds bring higher temperatures and the majority of the annual rainfall; and a "dry" season occurring between May and November with lower temperatures and a strong constant southeastern trade wind. The mean average rainfall is 1,089 mm, ranging between 547 mm and 1,467 mm (Stoddart 1983). The annual range of mean monthly temperatures (24.9°C - 28.4°C) is less than the mean daily minimum and maximum fluctuations (22.2°C - 31.2°C) (Stoddart and Mole 1977).

Aldabra is one of the largest raised coral atolls in the world with an elevation generally between 4 to 8 m above sea level (Stoddart et al. 1971). The major topographical relief is vegetated sand dunes along the south coast of Grande Terre. The largest dunes, Dune Jean-Louis and Dune d'Messe, rise to approximately 18 m above sea level (Stoddart et al. 1971). Soils on Aldabra are generally shallow (10-20 cm), and bare rock often comprises 50% of any given area (Trudgill 1979). The surface morphology can be generally distinguished, albeit oversimply, between 2 types of limestone: champignon and platin. Most of Aldabra consists of champignon which is characterized by irregular, deeply pitted, and sometimes very jagged surfaces. Most of the 83 km of coastline is champignon, with only 4.5 km consisting of scattered pocket beaches mostly located on the western end of the atoll (Gibson 1979). Platin limestone covers approximately 28% of Aldabra (Stoddart et al. 1971) and occurs mainly on Ile Picard and the eastern part of Grande Terre. Platin is relatively smooth pavement-like limestone that contributes to greater soil formation and is capable of supporting a variety of vegetation.

The vegetation of Aldabra is largely determined by the surface morphology (Fosberg 1971). Four general vegetation zones can be characterized on Aldabra:

mangroves, Pemphis scrub, mixed scrub, and coastal grassland. Mangroves border the lagoon and cover almost 20% of the land area (Stoddart and Fosberg 1984). Pemphis scrub grows in the champignon substrate and covers about one-half the land area of Aldabra (Gibson and Phillipson 1983). This scrub is dominated by Pemphis acidula -- a microphyllous evergreen shrub that grows densely to heights of 6 m. Much of the plain area of eastern Grande Terre consists of a more open mixed scrub and woodland community which varies in density, height, and species composition representing a number of taxa (Fosberg 1971, Hnatiuk and Merton 1979). The coastal grassland area is found along the south and east coast of Grande Terre although occasional patches can be found inland. This grassland is dominated by Sclerodactylon macrostachyum which grows in tussocks from 5 - 50 cm in height depending on grazing pressure, and Sporobolus virginicus which grows to 10 - 20 cm in height (Hnatiuk and Merton 1979).

A staffed Research Station is located on the southwest part of Ile Picard. There are 5 field camps on Grande Terre -- 4 are along the coast (Cinq Cases, Dune Jean-Louis, Dune d'Messe, and Anse Mais) and 1 near the lagoon (Takamaka Camp). Trails are maintained through the Pemphis scrub between the lagoon and the coast at each campsite. There are three field camps on Ile Malabar (Middle Camp, Anse Malabar, and Camp Gionnet). Travel between the Research Station and field camps is strictly by boat and limited by tides and winds; travel on the islands is by foot.

### Study Design

From October 1993 - May 1994 and November 1994 - May 1995, feral goats were killed on Aldabra Atoll by 2 shooters using bolt-action .223 caliber rifles with 3 x 9 telescopic sights. Hunting on foot was the most feasible method to control feral goats on Aldabra due to the size of the islands, distance from Mahé, density of vegetation, the number of non-target organisms, and the protected status of a World Heritage Site. At the beginning of each field season both shooters hunted as a team, but as goats became more difficult to locate, each shooter hunted alone to maximize time, effort, and area covered per day. A chi-square test and 2 x 2 contingency table (Zar 1984) was used to compare the efficiency of 2-shooters working as a team and

1-shooter working alone. A typical period in the field was between 4 - 10 days. Time in the field was restricted due to tides, winds, lack of freshwater, and availability of boats and Research Station personnel. The original project was planned for a 1-year field season, but most of the field equipment was lost in a boat accident after 6 months, and the project was recontinued for a second 6-month season. At the outset of the campaign, a relatively large feral goat population was present on Grande Terre, with remnant goat populations existing on Ile Picard and Ile Malabar. Initially, time was spent eradicating the remnant goat populations, and control did not begin on Grande Terre until January 1994. To assist in control efforts, the Judas goat technique was employed using 20 radio collars (Telonics, Inc., U.S.A.) with an approximate range of 1.5 km. A total of 28 Judas goats were used atoll-wide during the entire project -- 2 on Ile Picard, 6 on Ile Malabar, and 20 on Grande Terre. All Judas goats were chased on foot and captured by hand. Six goats were captured using a flashlight on a moonless night, while the remainder were captured in daylight in the open coastal zone of Grande Terre (except 1 captured at Dune Jean Louis) with 2 or more people.

Based on logistical and physiographical differences, I divided Grande Terre at Pt. Lion into 2 areas -- West Grande Terre (WGT) and East Grande Terre (EGT). To compare the Judas goat technique with traditional hunting methods during the initial stages of a control campaign, I further divided EGT into a north (CCN) and south (CCS) zone approximately 1 km south of the Cinq Cases field camp, and marked this boundary using fishing net floats placed on stakes and in trees. Control efforts occurred in the Cinq Cases area for 9 periods ranging from 5-14 days during the 2 seasons. Due to the difficulty of defining specific visitations to WGT, control periods were divided into 9 periods based on months from January 1994 - April 1994 and November 1994 - March 1995. Each period on WGT represents 2 - 15 days.

Three Judas goats were captured and released in CCS and CCN (other goats were released later). At the outset of the campaign, CCN was randomly selected to be hunted using both the Judas goat technique and traditional hunting methods, while CCS was hunted using only traditional means. Hunting with Judas goats began in CCS when it was decided too few goats were being killed. Traditional hunting methods

involved hiking around, watching for goats or goat sign, and listening for bleating goats. We also watched for cattle egrets (Bubulcus ibis) which tended to congregate around goats. I compared the kill rates (goats killed/hr) for CCN and CCS during the first 3 periods using a paired t-test. I compared Judas goat hunting and traditional hunting methods on EGT during the last 5 periods using multiple linear regression; kill rate was the dependent variable, with period and hunting method as independent variables.

Only female goats were used as Judas goats because they were reported to be more successful than males in locating and joining conspecifics (Taylor and Katahira 1988). Offspring of Judas goats were killed as soon as possible to encourage Judas goats to locate conspecifics, otherwise post-partum females separate from other goats (Yocum 1967, Rudge 1969, Shackleton and Shank 1984) and associate exclusively with their offspring from a month to over a year (Rudge 1970). Killing the offspring also caused females to return to estrus sooner, which attracted male goats. Because of their gregarious nature and findings that Judas goats continue to locate other goats even when a population is nearly eradicated (Keegan et al. 1994a), a Judas goat found alone or with another Judas goat was accepted as evidence of a lack of goats in its home range. When Judas goats did associate with one another for a period of time, one was killed to encourage the survivor to locate other conspecifics. Recapturing a Judas goat was not feasible. Judas goats were considered killed when originally captured and were not included in subsequent kill rates or group sizes.

To determine if residency improved efficiency of a Judas goat, 13 goats were released at their capture sites, while 7 were transported by boat and/or foot and released in other areas of Grande Terre. Goats captured and released at the same site were considered residents, while those transported at least 7.5 km from their capture site were considered non-residents (Goats transported less than 7.5 km ( $n = 2$ ) returned to their original capture location.) The amount of time Judas goats were held captive was minimized as much as possible, but some goats were held overnight and one was captive for 65 hours before being released. No mortalities resulted from captivity.

To determine if a younger animal improved efficiency of a Judas goat, all Judas goats were aged based on tooth eruption and replacement (Silver 1963) at the time of capture. Of the 20 Judas goats on Grande Terre, 16 were included in the analysis. (Three died of natural causes and 1 was killed due to a faulty radio collar.) Judas goats were divided into 3 age classes ( $< 1.0$  yr,  $1.0 - 2.0$  yr, and  $> 2.0$  yrs) and compared with the number of conspecifics killed using linear regression. To determine if female Judas goats of different ages biased the sex and ages of goats killed, sex and age ratios were compared with chi-square tests and  $2 \times 2$  and  $2 \times 3$  contingency tables, respectively (Zar 1984). Age classes of goats killed were divided into 2 age classes ( $< 2.0$  yrs and  $> 2.0$  yrs).

To determine home range sizes and travel distances, locations of Judas goats were recorded when possible. Locations were determined using radio receivers and either locating the goat visually, following closely through the vegetation as determined by radio signal or sounds made by the goat, or by triangulation using fixed points along the coastline or other topographic features. Judas goat locations were placed on a detailed vegetation map in the field and then transferred to a  $100 \text{ m} \times 100 \text{ m}$  grid map at the Research Station. Home range size of Judas goats was determined using CALHOME (Kie et al. 1996) and the minimum convex polygon method (Hayne 1949). The maximum distance travelled was defined as the longest axis of the observed home range. Linear regression was used to determine the relationship of Judas goat home range to months of service as a Judas goat, number of locations obtained, maximum travel distances, and conspecifics killed.

To determine hunting and Judas goat efficiency, the following data were collected: date, time, and location when goats were encountered; presence or absence of Judas goats; number of goats encountered prior to shooting; number, sex, and age of goats shot; number of shots fired; number of goats that escaped; and time spent hunting. An encounter was defined as any instance a goat was encountered when a shot was possible. The number of goats in a group included any goat within 50 m of one another which exhibited similar activities. Ages of dead goats were determined by tooth eruption and replacement (Silver 1963). An escapee was defined as a goat that

was approached close enough to be shot, but (1) escaped while the hunter targeted other animals in the group, (2) the hunter missed, (3) a shot could not be taken due to safety considerations or the location of a Judas goat, or (4) a wounded goat that was not recovered. Sex, age, and coat colors of escapees were noted when possible to recognize individuals when later encountered and killed. Time spent hunting was recorded to the nearest 5-minute interval, and times ended at the last effective daylight. Six goats were shot in moonlight or by flashlight, but they were not included in the analysis. Judas goat hunting times were determined to be the time when the hunter was in pursuit of a Judas goat; walking to the general area or leaving the site of a Judas goat was considered traditional hunting time. The Leslie-Davis (1939) removal method of population estimation was used to estimate the number of remaining goats and compared with our subjective estimation of goats remaining.

## RESULTS

From October 1993 - May 1994 and November 1994 - May 1995, a total of 832 goats were killed on Aldabra Atoll using both the Judas goat technique and traditional hunting methods. A total of 28 Judas goats were used during the entire campaign.

The goat populations on Ile Picard and Ile Malabar were eradicated during the first season. On Ile Picard, 2 Judas goats were used and 13 goats were killed in October-November. On Ile Malabar, 6 Judas goats were used--3 resident and 3 non-resident--and 19 goats were killed in October-December. On Ile Picard and Ile Malabar, 8 goats in 4 groups (62%) and 13 goats in 6 groups (68%) were with Judas goats, respectively. The time from the first control effort to the last non-Judas goat being killed was 3 and 6 weeks on Ile Picard and Ile Malabar, respectively. However, both islands were continually checked for goat sign and conspecifics with Judas goats for 4 - 5 months afterwards.

On Grande Terre, a total of 798 (374 M: 424 F) goats were killed (including 5 Judas goats captured on Grande Terre and released on Ile Picard and Ile Malabar, 17 Judas goats on Grande Terre, and 6 other goats killed while capturing Judas goats).



A total 2,086.3 hunter hours on Grande Terre resulted in the killing of 770 goats with 1,280 shots (1.66 shots/goat). The overall kill rate was 0.37 goats killed/hour. During the first season, 472 goats were killed; 298 were killed during the second season. A total of 1,042 goats were encountered (0.50 goats encountered/hr) of which 26.1% escaped, although many of those goats were re-encountered and killed later. Mean group size was 3.2 (SD = 2.4) with a range of 1 to 20. Feral goats were not evenly distributed throughout Grande Terre. Densities in WGT and EGT were 3.6 goats/km<sup>2</sup> and 12.1 goats/km<sup>2</sup>, respectively. The greatest number of goats killed occurred in the Cinq Cases-Takamaka region (Figure 1.2).

Twenty Judas goats were used on Grande Terre, 18 captured in the first season and 2 in the second; 13 were resident and 7 were non-resident goats. Of the 770 goats killed, 211 (27.4%) were with Judas goats; 18.0% (n = 85) of the first season total and 42.3% (n = 126) of the second season total were in the presence of Judas goats. The number of Judas goats in use at any time in an area was variable depending on the movement of the Judas goats, and death from natural causes or being shot. Of the original 20 Judas goats on Grande Terre, 10 were in EGT and 10 were in WGT. However, as the project progressed, 3 died of natural causes, 1 was shot due to a faulty radio collar, and 7 were killed when they began exclusively associating with other Judas goats. Of the remaining 9 that were killed at the completion of the project, 6 were in EGT and 3 were in WGT.

As control activities continued on EGT, goats killed/hour decreased from a high of 2.05 during the initial control period to 0.03 at the end of the campaign (Figure 1.3). Both CCN and CCS had roughly the same overall population with 270 and 260 goats killed during the entire project, respectively. Period 4 represents the first time Judas goat hunting was used in CCS, and concentration of hunting effort further inland in CCN. CCS with only traditional hunting had higher, although not statistically significant ( $t = 1.83$ ;  $P > 0.05$ ), kill rates (goats killed/hr) over the first 3 periods (3.17, 0.56, and 0.70) than CCN with traditional and Judas goat hunting (1.27, 0.40, and 0.22). In CCN and CCS, 37.4% and 11.6% of all goats encountered while Judas goat hunting escaped, respectively; 19.7% and 19.6% of all goats encountered while



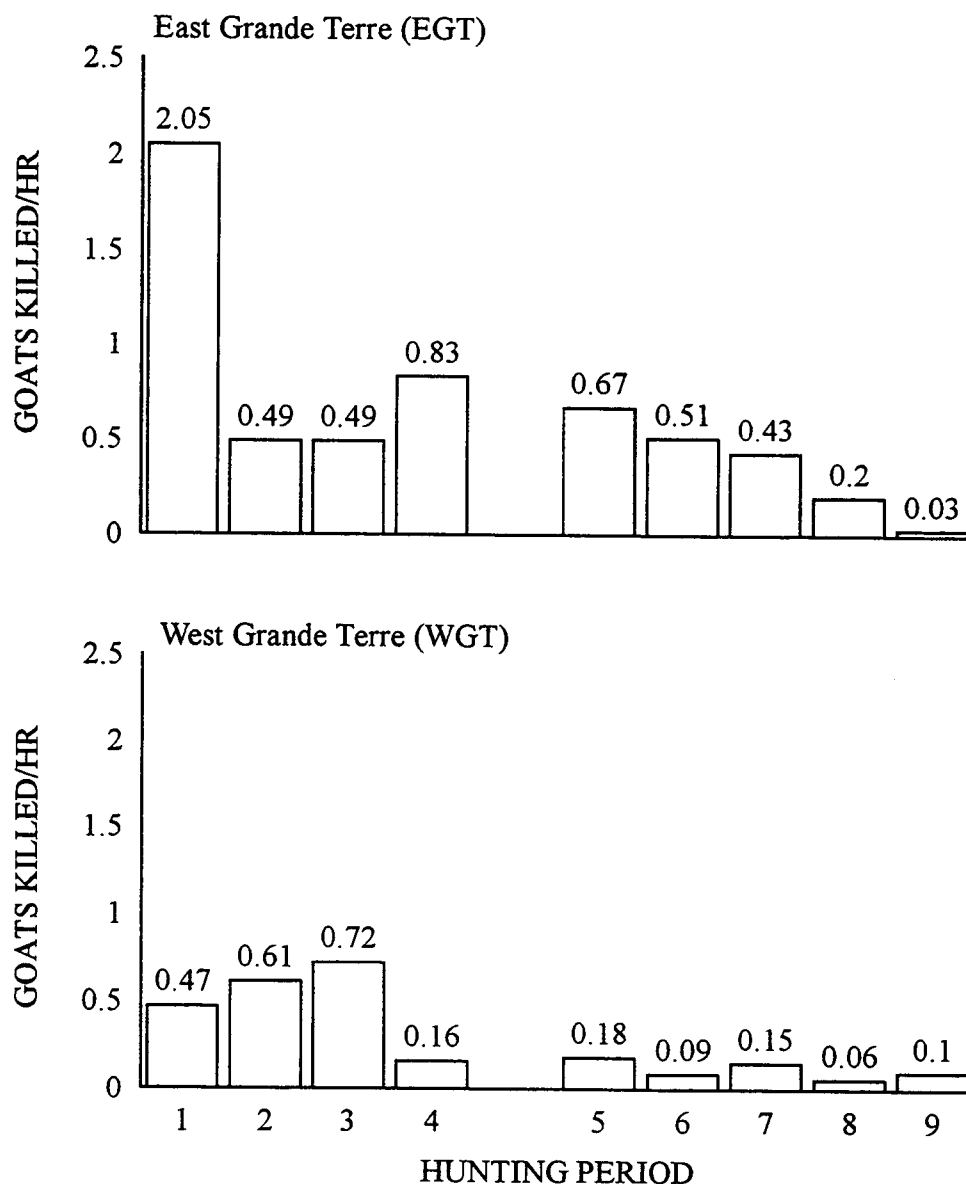


Table 1.3 Feral goats killed/hr for each hunting period on East Grande Terre (EGT) and West Grande Terre (WGT), Aldabra Atoll. On EGT, each bar represents a period in the field which averaged 4 - 9 days. Periods 1 - 4 represent the first season from Jan - Apr 1994; Periods 5 - 9 represent the second season from Dec - Apr 1995. Period 4 represents the first time Judas goat hunting was used in CCS, and concentration of hunting effort further inland in CCN. On WGT, each bar represents each month of hunting effort. Periods 1 - 4 represents the first season from Jan - Apr 1994; Periods 5 - 9 represent the second season from Nov 1994 - Mar 1995. Period 3 represents when more than 2 Judas goats were in service.

traditional hunting escaped, respectively. Mean group size in CCS decreased from 4.0 (SD = 3.1) during the first season to 3.0 (SD = 1.9) during the second; mean group size in CCN decreased from 3.4 (SD = 2.4) during the first season to 2.7 (SD = 2.1) during the second.

Goats killed/hour also decreased on WGT as control activities continued from a range of 0.47 - 0.72 during the first 3 months of the control effort, to 0.06 - 0.18 during the next 6 months of control (Figure 1.3). Period 3 represents when more than 2 Judas goats were in service in WGT. A total of 161 goats were killed in the first season (49% of those were killed in the first month) and 79 in the second. In WGT, 29.0% of all goats encountered while Judas goat hunting escaped, while 29.8% of all goats encountered while traditional hunting escaped. Mean group size in WGT decreased from 3.4 (SD = 2.3) during the first season to 2.4 (SD = 1.4) during the second.

Kill rates (goats killed/hr) were similar in the first season of the campaign between Judas goat hunting and traditional hunting in CCN (0.77 vs. 0.81), CCS (1.32 vs. 1.25); and WGT (0.45 vs. 0.35). However, Judas goat hunting became increasingly important over time in both EGT and WGT (Figure 1.4). During the second season, the kill rates for Judas goat hunting were greater than traditional hunting in CCN (0.84 vs. 0.22), CCS (1.00 vs. 0.30), and WGT (0.27 vs. 0.08). Although the kill rates between the two methods were not statistically significant ( $t = 0.91$ ;  $P > 0.05$ ), the overall kill rate for the project was almost 2 times greater for Judas goat hunting (0.61 goats killed/hr) than traditional hunting (0.32 goats killed/hr). Using multiple linear regression to compare Judas goat hunting and traditional hunting in Periods 5 - 9 on EGT (Figure 1.5), Judas goat hunting was approximately 70% more effective ( $F = 16.58$ ;  $df = 9$ ;  $P = 0.002$ ) than traditional hunting. However, an interaction term between period and method was also significant ( $F = 42.95$ ;  $df = 9$ ;  $P = 0.0002$ ), which indicates other influences such as changing goat density and distribution, increased wariness of goats, and increased knowledge and experience of the shooters.

Of the 16 Judas goats included in the analysis (Table 1.1), 9 were located in EGT and 7 were in WGT; 5 were 0 - 1 year, 6 were > 1 - 2 years, and 5 were > 2 years; and 10 were residents and 6 were non-residents. The mean Judas goat home range in

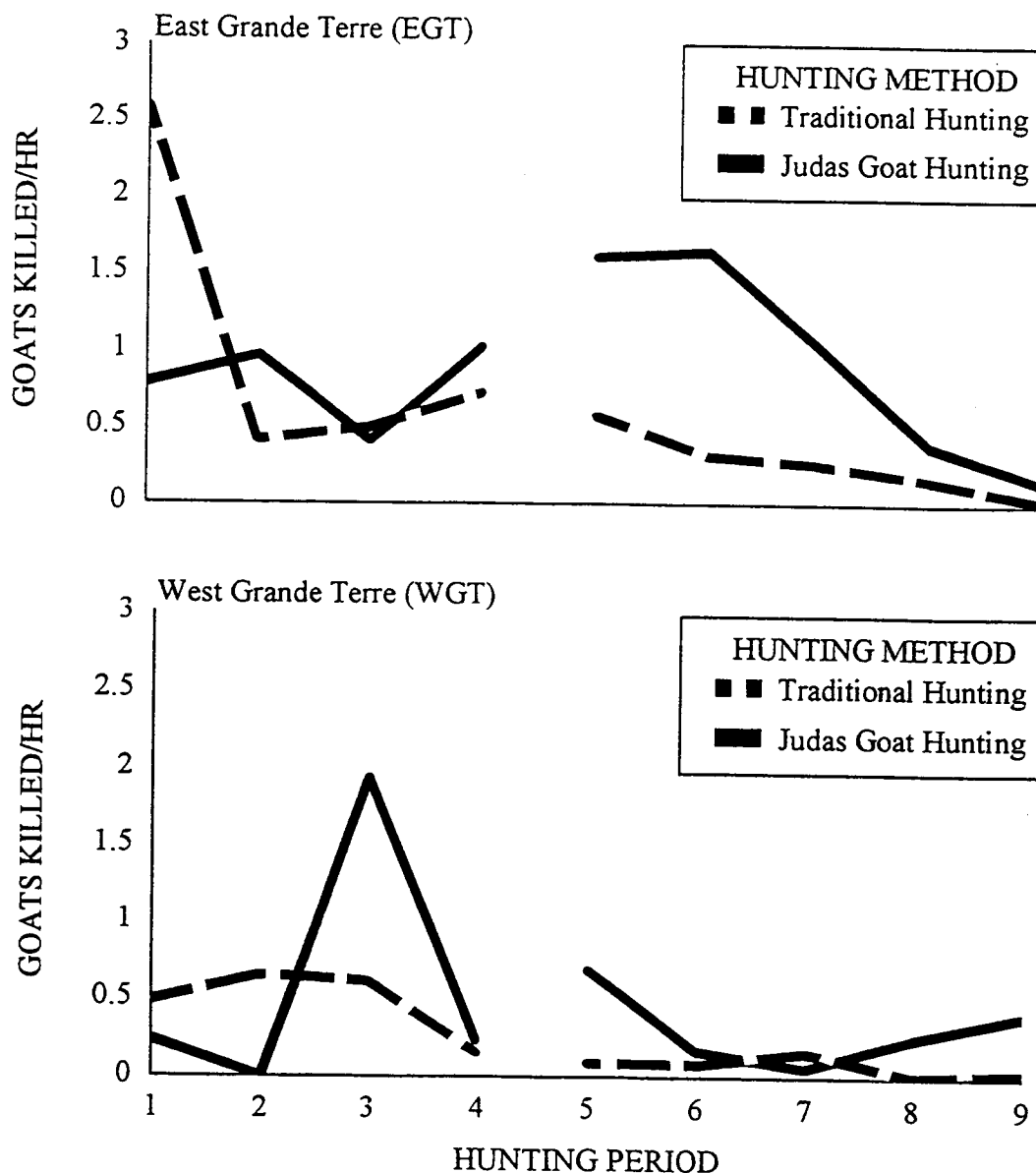


Table 1.4 Feral goats killed/hr using traditional hunting and Judas goat hunting during each period on East Grande Terre (EGT) and West Grande Terre (WGT), Aldabra Atoll. Periods 1 - 4 represent the first season (Jan - Apr 1994); Periods 5 - 9 represent the second season on EGT (Dec 1994 - Apr 1995) and WGT (Nov 1994 - Mar 1995). Periods 1 - 3 on EGT represent the use of Judas goats on CCN only. Period 3 on WGT represents the first time more than 2 Judas goats were in service. Period 7 on WGT represents a concentration of hunting effort near Pt. Lion where no Judas goats were present.

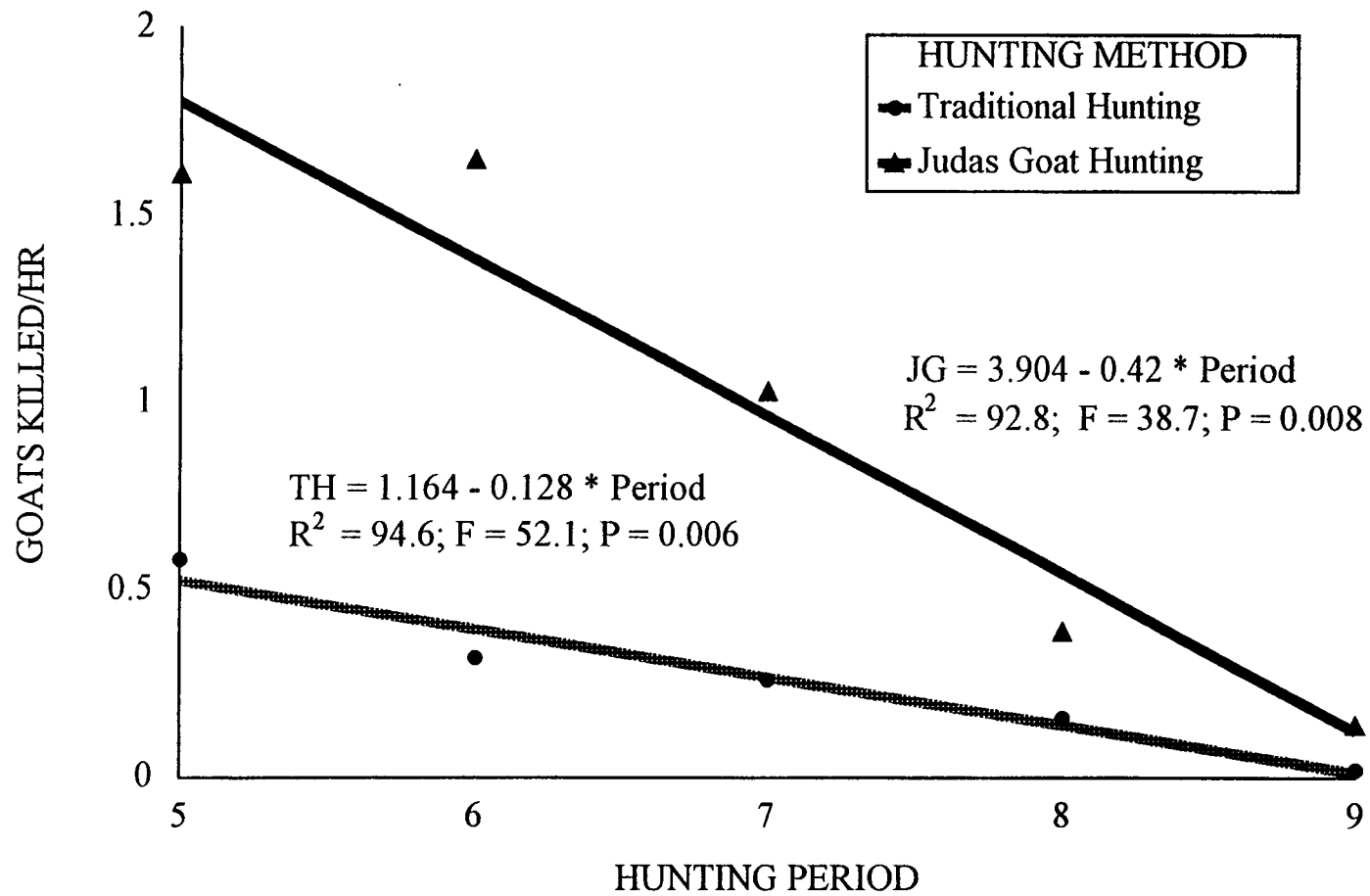


Figure 1.5 Comparison of kill rates between Judas goat hunting and traditional hunting in Periods 5 - 9 on EGT, Aldabra Atoll.

Table 1.1 Judas goat home ranges, maximum travel distances, and conspecifics killed. Conspecifics killed in this table also include those goats killed with Judas goats during traditional hunting methods in CCS during Periods 1 - 3.

| Judas Goat No. | Area | Residency | Age (yrs)   | Home Range (km <sup>2</sup> ) | Max. Travel Dist. (km) | Goats Killed |
|----------------|------|-----------|-------------|-------------------------------|------------------------|--------------|
| 1              | EGT  | Non-Res   | > 2.0       | 0.73                          | 1.75                   | 9            |
| 2              | WGT  | Non-Res   | > 1.0 - 2.0 | 2.13                          | 2.07                   | 8            |
| 3              | EGT  | Resident  | > 1.0 - 2.0 | 8.25                          | 6.25                   | 37           |
| 4              | WGT  | Resident  | > 2.0       | 2.39                          | 3.15                   | 19           |
| 6              | EGT  | Resident  | > 2.0       | 2.11                          | 1.85                   | 11           |
| 7              | WGT  | Non-Res   | < 0.5       | 1.87                          | 2.4                    | 7            |
| 9              | EGT  | Resident  | > 0.5 - 1.0 | 4.03                          | 2.7                    | 28           |
| 10             | WGT  | Resident  | > 1.0 - 2.0 | 1.63                          | 3.8                    | 6            |
| 11             | EGT  | Resident  | > 0.5 - 1.0 | 2.9                           | 3.9                    | 32           |
| 12             | EGT  | Resident  | > 2.0       | 14.17                         | 6.95                   | 40           |
| 14             | WGT  | Non-Res   | > 2.0       | 2.46                          | 3.1                    | 10           |
| 15             | EGT  | Resident  | > 0.5 - 1.0 | 3.75                          | 4.72                   | 12           |
| 16             | EGT  | Resident  | > 1.0 - 2.0 | 5.49                          | 6.9                    | 1            |
| 17             | WGT  | Non-Res   | > 1.0 - 2.0 | 0.3                           | 3.3                    | 1            |
| 18             | EGT  | Resident  | > 0.5 - 1.0 | 3.86                          | 3.8                    | 24           |
| 21             | WGT  | Non-Res   | > 1.0 - 2.0 | 1.8                           | 3.6                    | 5            |

EGT was  $5.03 \text{ km}^2$  ( $SD = 4.03 \text{ km}^2$ ) and ranged from 0.73 to  $14.17 \text{ km}^2$ ; the mean maximum distance travelled for Judas goats in EGT was 4.31 km ( $SD = 2.04$ ) with a range of 1.75 to 6.95 km. The mean Judas goat home range in WGT was  $1.80 \text{ km}^2$  ( $SD = 0.73$ ) and ranged from 0.30 -  $2.46 \text{ km}^2$ ; the mean maximum distance travelled was 3.60 km ( $SD = 0.62$ ) ranging from 2.07 to 3.80 km. Analyzing EGT and WGT separately, I found no significant relationship between home range size and either the number of locations ( $F = 1.09$  and  $2.73$ ;  $df = 8$  and  $6$ ;  $P = 0.33$  and  $0.16$ ) or the number of months a Judas goat was in service ( $F = 0.33$  and  $0.01$ ;  $df = 8$  and  $6$ ;  $P = 0.58$  and  $0.92$ ), so goats ranging from 8 - 60 locations and 3 - 16 months of service were combined. The relationship between the maximum distance goats travelled and home range size was significant on EGT ( $F = 0.01$ ;  $df = 8$ ;  $P = 0.01$ ), but not on WGT ( $F = 0.45$ ;  $df = 6$ ;  $P = 0.53$ ).

The number of recorded encounters of Judas goats with conspecifics ranged from 1 to 21, numbers of conspecifics encountered ranged from 1 to 65, conspecifics killed with Judas goats ranged from 1 to 40. There was a significant relationship between home range size and the number of conspecifics killed in both EGT and WGT ( $F = 5.55$  and  $6.85$ ;  $df = 8$  and  $6$ ;  $P = 0.05$  and  $0.05$ ) (Figure 1.6). There is no significant relationship between the age of Judas goats and the number of conspecifics killed ( $F = 0.01$ ;  $df = 15$ ;  $P = 0.91$ ). Sex ratios of goats killed in the presence of female Judas goats did not differ from a theoretical 1:1 sex ratio ( $\chi^2 = 0.004$ ,  $P < 0.05$ ) or the sex ratio of all goats killed during the study ( $\chi^2 = 0.30$ ,  $P < 0.05$ ); sex ratios of goats killed also did not differ among the different age classes of Judas goats ( $\chi^2 = 2.18$ ,  $P < 0.05$ ). Age ratios of goats killed in the presence of Judas goats did not differ from the age ratio of all goats killed during the study ( $\chi^2 = 1.45$ ,  $P < 0.05$ ); age ratios also did not differ among the different age classes of Judas goats ( $\chi^2 = 2.29$ ,  $P < 0.05$ ).

The apparent efficiency on EGT of 2-shooters working as a team (1.14 goats killed/hr) versus 1-shooter working alone (0.38 goats killed/hr) is an artifact of hunting together when goat densities were greatest. Hours of hunter effort hunting alone was 3 times greater ( $n = 695$ ) than hours spent hunting together ( $n = 232$ ), however, the total number of goats encountered and killed while hunting alone ( $n = 353$  and  $265$ ,



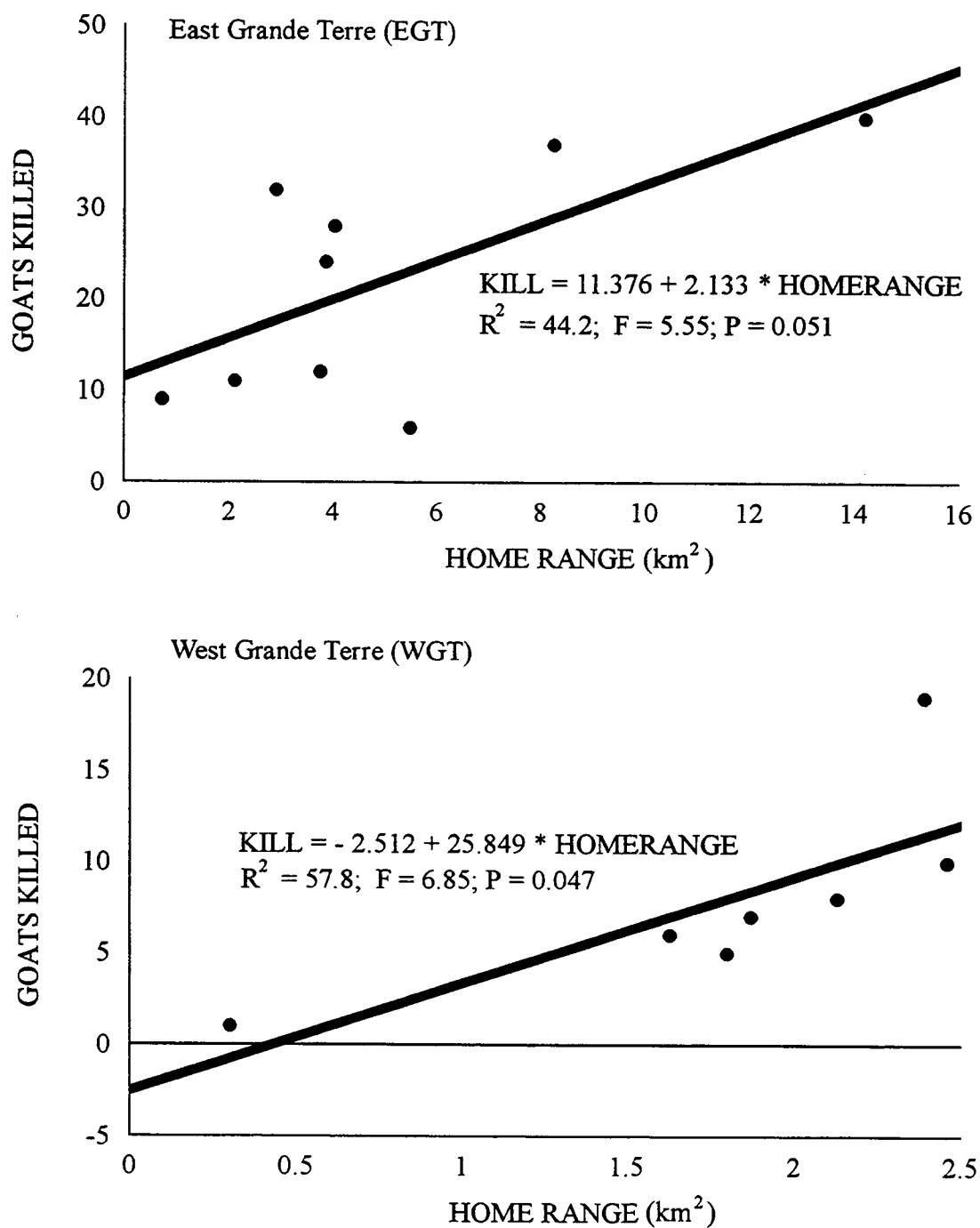


Figure 1.6 Home range size and numbers of goats killed with each Judas goat between January - April 1994 and December 1994 - May 1995 on EGT and WGT, Aldabra Atoll.

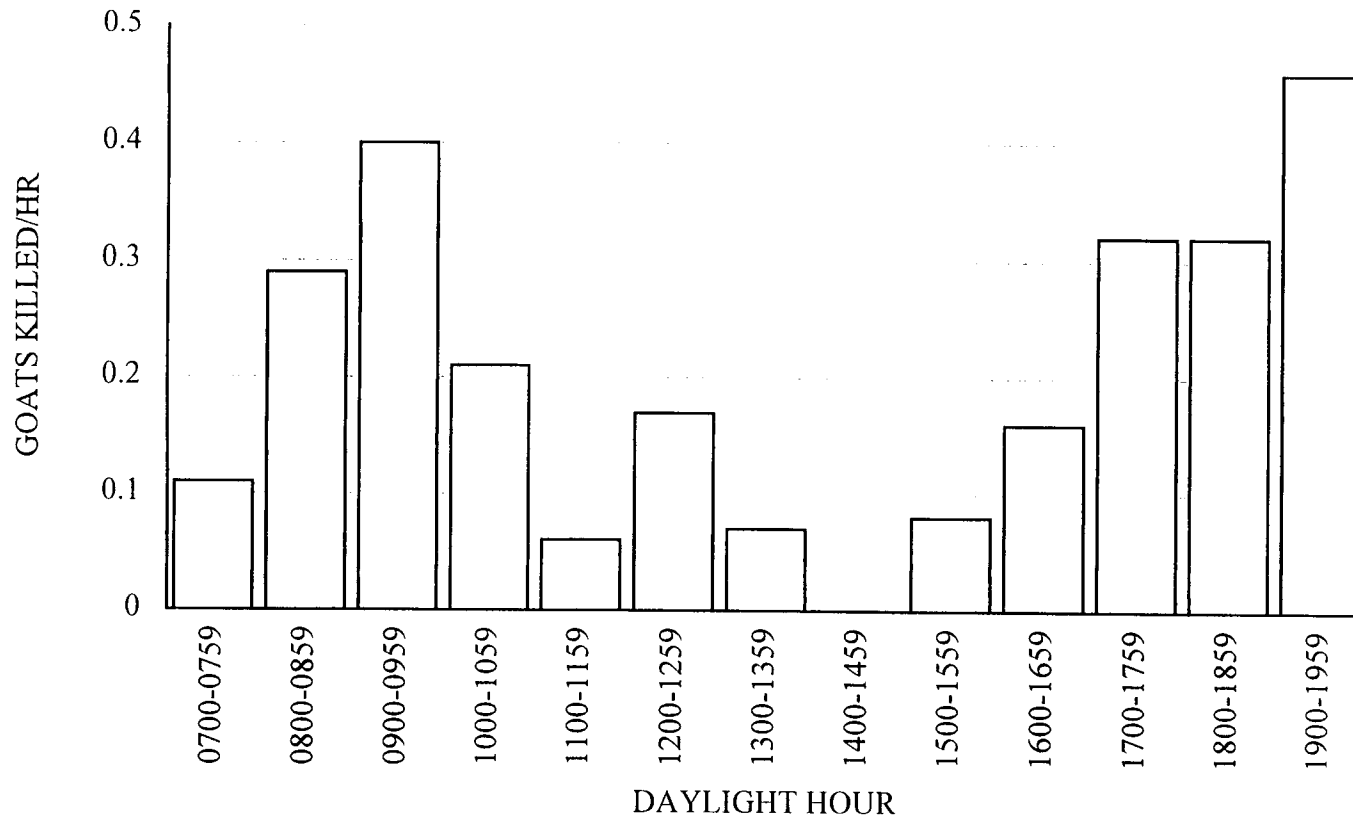


Figure 1.7 Mean numbers of feral goats killed/hr for each daylight hour from 24 Nov 94 - 23 Apr 1995 on Grande Terre, Aldabra Atoll. Typical daylight hours were between 0700 and 1930. Hunting hours were not recorded when it became too dark to see. No hours are included for the first season due to the loss of field notebooks during a boat accident.

respectively) and hunting together ( $n = 344$  and  $265$ , respectively) was not different ( $\chi^2 = 0.12$  and  $0$ ,  $P < 0.05$ ). Therefore, shots fired and escape rates were compared between hunting alone and together. Mean group size encountered while hunting together ( $\bar{x} = 4.0$ ;  $SD = 2.9$ ) was greater than when hunting alone ( $\bar{x} = 2.8$ ;  $SD = 2.1$ ); likewise, significantly more shots were fired when hunting together ( $n = 509$ ,  $1.92$  shots/goat killed) than hunting alone ( $n = 388$ ,  $1.49$  shots/goat killed;  $\chi^2 = 15.30$ ,  $P < 0.05$ ). However, there was no difference in the number of goats that escaped ( $\chi^2 = 0.48$ ,  $P < 0.05$ ). The optimum hunting hours on Aldabra were 0800-0959 and 1700-1959 when  $0.29 - 0.46$  goats killed/hour (Figure 1.7).

## DISCUSSION

Although traditional hunting is an efficient control method when goat densities are high, Judas goat hunting is a more efficient control method for remnant goat populations as evidenced by the eradication of goats on Ile Picard and Ile Malabar, as well as HVNP (Taylor and Katahira 1988) and SCI (Keegan et al. 1994a). In this study, 42.3% of all goats killed in the second season (126 of 298) were in the presence of Judas goats; kill rates during the second season were 3 - 4 times greater for Judas goat hunting than traditional hunting in all 3 areas of Grande Terre -- CCN ( $0.84$  vs.  $0.22$  goats killed/hr), CCS ( $1.00$  vs.  $0.30$  goats killed/hr), and WGT ( $0.27$  vs.  $0.08$  goats killed/hr). Kill rates for Judas goat hunting was more efficient for all 6 hunting periods (Periods 4 - 9) in EGT when both Judas goat and traditional hunting methods were used (Figure 1.4), and approximately 70% more effective during the entire second season (Figure 1.5).

There was a significant relationship between home range size and the number of conspecifics killed in both EGT and WGT. The greater the home range of a Judas goat, the more likely they are to find conspecifics. Individual goats rapidly adopt fixed home ranges, but they vary considerably among individuals. Home range sizes of Judas goats on EGT ( $\bar{x} = 5.03 \text{ km}^2$ ) and WGT ( $\bar{x} = 1.80 \text{ km}^2$ ) were comparable to home ranges of other insular feral goat populations (Riney and Caughley 1959, Yocum 1967, Coblentz

1974, O'Brien 1984, Keegan et al. 1994a). The maximum distance travelled by Judas goats is significantly related to home range size in EGT but not WGT, probably due to the narrowness of that part of the island. The mean maximum distance travelled by Judas goats on EGT ( $\bar{x}$  = 4.31 km) and WGT ( $\bar{x}$  = 3.60 km) is similar to the average distance of 4.8 km Judas goats travelled on SCI (Keegan et al. 1994a). The maximum distance a female Judas goat travelled in HVNP was 6.2 km (Taylor and Katahira 1988). A Judas goat in EGT travelled a straight-line distance of more than 3.5 km in a 32-hour period; 1 herd in Halekala N.P. was observed to have moved over 2 miles (3.22 km) in a day (Yocum 1967). Like previous studies in HVNP and SCI, Judas goats could not be monitored on a consistent basis (Taylor and Katahira 1988, Seward 1991), thus minimum contact times with conspecifics and daily movements could not be determined.

The age of the Judas goat does not appear to be important in associating with conspecifics, nor do female Judas goats bias the sex or ages of goats killed. Due to logistical difficulties and the difference in goat densities in EGT and WGT, no conclusion could be made whether resident or non-resident goats were more effective. Of the goats analyzed, only 1 of 9 Judas goats on EGT was a non-resident while 2 of 7 goats on WGT were residents.

Only 9 of the original 20 Judas goats on Grande Terre remained at the conclusion of the project -- 3 died of natural causes, 1 was shot due to a faulty radio collar, and 7 were killed when they began exclusively associating with other Judas goats. Of the 9 remaining goats, only 3 were in WGT and 6 were in EGT. The lack of goats in WGT decreased the chances to find more goats, as did a lack of goats in other areas such as Anse Takamaka where both Judas goats that were captured died of natural causes.

Six of the remaining 9 Judas goats were no longer effective Judas goats. Although there was no easy way to quantify the effectiveness of a Judas goat, my definition of an effective Judas goat was one that could be approached within 50 m before taking flight, wide-ranging and actively sought out conspecifics, and not constantly inhabiting dense vegetation. Capturing Judas goats in the beginning of the

project and continually shooting near them caused some to become increasingly wary and more difficult to use at the end of the project when they were needed most. Other goats were wary during the very beginning. The approximate 6-7 month period between seasons did not decrease wariness of Judas goats. In fact, almost all Judas goats gave birth during that time or shortly after the second season began, which made them even more wary, possibly due to natural wariness at parturition. Gould (1979) found that post-partum goats were the most difficult animals to approach, and would be the first to leave an area at the first indication of human presence.

The use of Judas goats has not always been found effective. On Aguijan Island, Commonwealth of the Marianas, kill rates of 1.67 and 1.43 goats killed/hunter day were achieved by traditional hunting and Judas goat hunting, respectively (Rice 1991). Although Judas goat hunting was not significantly different from traditional hunting on Aguijan (Rice 1991), 75% of the population had been removed with an estimated 40 goats remaining, so Judas goats may have had increased efficiency if the program had continued.

Traditional hunting is an efficient control method when goat densities are high, as demonstrated by comparing the kill rates between Judas goat hunting and traditional hunting during the first season on CCN (0.77 vs. 0.81 goats killed/hr), CCS (1.32 vs. 1.25 goats killed/hr), and WGT (0.45 vs. 0.35 goats killed/hr). Goat populations and kill rates generally declined in both EGT and WGT as the project progressed. Of the 9 hunting periods in EGT (Figure 1.3), Period 4 was the only period that did not follow the downward trend, which was probably because it was the first time Judas goats were used in CCS, but also likely due to our increasing experience and concentration of hunting activity inland from the coast in CCN. WGT exhibited an increase in kill rates over the first 3 hunting periods (Figure 1.3), but this is probably due to the fewer hours hunted in Periods 2 (47.3 hrs) and 3 (37.3 hrs) than in Periods 1 (171.9 hrs) and 4 (171.6 hrs), as well as the increased use of Judas goats. Judas goat hunting became more effective than traditional hunting as goat densities declined.

Vegetation, terrain, and the need to minimize escapement imposed limitations on control efforts. Most shooting occurred within a range of 30 - 60 m due to the dense

vegetation and to reduce the chances of goats escaping. If it was possible to remain concealed so that goats did not see the shooters, their first reaction to gunshots would be to clump together and remain standing in an alert position until the threat was detected. If shooters were spotted, the goats would usually run into cover as quickly as possible. With the exception of when large groups were known to occur, or when hunting in the initial phase of the campaign when groups were more likely to be encountered, it was not efficient to hunt as a team. Hunting alone increased the area that could be covered, fewer total shots were fired, and numbers of escapees did not differ. In many places on Aldabra, due to the vegetation and terrain, 2 hunters could not shoot at the same time, so there was no advantage of increased firepower. Hunting in pairs or trios also did not affect hunting effectiveness on Aguijan (Rice 1991), and Coblentz et al. (1990) found a 3-person shooting team was a trade-off between increased firepower and increased risk of alarming goats. However, during their 1987-1988 control effort, the highest kill rates (5 goat/hr) and lowest expenditure of ammunition (1.4 shots/goat killed) was achieved with a 2-person shooting team (Coblentz et al. 1990).

Although escapees were not statistically different between hunting alone or together, it was still a significant problem as any shooting control program should minimize the number of goats that survive encounters with shooters. The overall escape rate of 26.1 % is considerably less than the 52.7 % escape rate on Aguijan (Rice 1991), but higher than the 11 - 20 % reported elsewhere (Parkes 1983, Parkes 1984, Coblentz et al. 1990). The slightly higher rate of escapees may be an artifact of my strict definition (e.g., goats wounded and not recovered), however, the rate of escapees was also related to group size ( $\bar{x} = 3.2$ ;  $n = 324$  groups; range 1 - 20), the situation when goats were encountered, and general wariness. If groups of  $> 8$  ( $n = 21$ ) are excluded from the analysis, then the overall escape rate is 22.1%; the escape rate is 19.6 % if groups  $> 5$  ( $n = 65$ ) are excluded. Despite the relatively high rate of escape, many of the escaped goats were re-encountered and killed later.

The dense vegetation and constricted coastal area in some regions of the island, resulted in many encounters with goats at very close range. The degree of escapability

when Judas goat hunting in CCN (38.9%;  $\bar{x}$  group size = 3.2) vs. CCS (10.3%;  $\bar{x}$  group size = 2.8) is an example of the difference between hunting in the mixed woodland/semi-open area of CCN and the more open terrain of CCS. Although the open habitat makes approaching a goat somewhat more difficult, it is easier to know where the goats are at all times, and affords more time to shoot before goats can reach cover if the shooter is spotted. Goats on Aldabra were very wary. Bounties were established by SIF to encourage the Research Station personnel to kill goats, which they ran down and killed with machetes. Although it may seem effective, this opportunistic hunting kills relatively few animals and makes the survivors increasingly wary (Daly and Goriup 1987; Daly 1989).

The optimum hunting hours of 0800-0959 and 1700-1959 (Figure 1.6) when the highest kill rates occurred corresponds with the 3 activity periods characterized by Burke (1988a) with movement and feeding occurring before 1130, resting during the hottest part of the day between 1130 and 1600, and another movement and feeding period after 1600. I also observed goats active on moonlit nights. Some goats in the Cinq Cases region also were actively feeding in the early afternoon in the open coastal areas, as also observed by Burke (1988a). During infrequent overcast days, goats could be found active throughout the day, but during wet weather goats appeared to take shelter as also observed by Riney and Caughley (1959) and Gould (1979). Although Burke (1988a) concluded that goats displayed a circadian pattern of migration to and from the coast, and most goats killed during this project and during 1987 and 1988 were encountered in the coastal zone (Coblentz et al. 1990), I found that goats did not display a daily movement pattern and some goats rarely if ever moved to the coastal areas when adequate open areas further inland could be utilized.

There is no possibility for natural movement of goats between islands on Aldabra. Passe Gionnet between Ile Polymnie and Ile Malabar has a maximum depth of 9 m and is 100 m wide (Gibson & Phillipson 1983); the main channel between Ile Picard and Ile Polymnie is 600 m wide, 18-22 m deep in deepest part, and flows at 6 knots at peak ebb tides; Passe Houareau between Ile Malabar and Grande Terre has a maximum depth of 15 m; and the deepest channel in the West Channels between Ile

Picard and Grand Terre is Passe Du Bois which is 5 m deep (Stoddart et al 1971). Goats can only recolonize with human assistance.

At the end of the project in May 1995 it was estimated that approximately 60-120 goats remained on Grande Terre in four separate inland areas (between Gros Ilot and north of Dune Blanc, north of Anse Quive, between Anse Takamaka and Takamaka camp, and south of Anse Cedres). Extremely low goat numbers were estimated as evidenced by Judas goats locating other Judas goats, Judas goats frequently found alone, the lack of fresh goat sign along the coastal areas or in clearings, and basal sprouting occurring below the 2 m browseline on Pemphis and Guettarda shrubs. This estimate was reinforced by a similar estimate of 84 goats determined by the Leslie-Davis (1939) removal method of population estimation. A total of 106 goats were killed during a third control effort from September 1996 to January 1997.

## MANAGEMENT IMPLICATIONS

Traditional hunting is an efficient means to control goats during the initial phase of a control program, but Judas goats allow eradication to be realized in an efficient and timely manner. If logistically feasible, intensive traditional hunting should proceed until goats are at a low level and then Judas goats should be released. Keegan et al. (1994a) recommended 1 Judas goat/2 km<sup>2</sup> as an approximate density to saturate most insular areas. Age of the Judas goat does not appear to be important, and it is unknown if residency effects kill rates. If Judas goats were not available from an outside source, goats could be captured at the outset of the project, but then not intentionally hunted until later in the project to decrease wariness in the latter stages of the campaign when Judas goats are needed most. Another factor to decrease wariness, is using radio-equipped tranquilizer darts (Kilpatrick et al. 1996) to assist in the capture of goats rather than chasing goats and capturing by hand. This method would also require fewer assistants, and provide the opportunity to be more selective, and to capture more easily approachable goats.



Hunting solo rather than a 2-person team appeared to be quite efficient, except in instances where a group of goats are known to occur or during intensive traditional hunting at the outset of a campaign when goat densities are greatest. Two-hunters working as a team would probably be more efficient on an island which is more open and less densely vegetated than Aldabra.

For any control campaign, there must be (1) a plan including an initial reconnaissance and monitoring period to familiarize control personnel with the area and determine the extent of the target population; (2) uninterrupted implementation of the control plan; (3) a monitoring program to ensure the target organism has been eradicated; and (4) sufficient resources to see the project through to a successful conclusion. The success of any control program does not depend on the number of animals killed, but on the numbers remaining. The Judas goat technique is an effective means of locating goats in low density populations and ensuring goats are killed at a rate greater than the rate at which they add individuals to the population. The Judas goat technique is a valuable conservation tool that can assist in maintaining the native biota of insular systems still plagued by feral goats.

### Chapter 3

## BIOLOGY OF FERAL GOATS

## ON ALDABRA ATOLL, REPUBLIC OF SEYCHELLES

### INTRODUCTION

Feral goats (Capra hircus) are a cosmopolitan ecological problem, particularly in insular systems where native biota have evolved in the absence of large mammalian herbivores (Coblentz 1978). Feral goats have seriously affected native vegetation (Furon 1958, Mueller-Dombois and Spatz 1974, Coblentz 1977, Hamann 1979, Cronk 1986) and wildlife (MacFarland et al. 1974, Franklin et al. 1979, Leathwick et al. 1983, Cruz and Cruz 1987) in numerous areas of the world. Feral herbivorous mammals are so destructive that it is virtually impossible to preserve or restore an island ecosystem without their elimination (Vitousek 1988).

Feral goats were first introduced to Aldabra Atoll (9° 24' S, 46° 20' E), Republic of Seychelles, sometime prior to 1878 (Stoddart 1981). Goats were most likely introduced to provide a source of meat for passing seafarers, and for a settlement later established on Ile Picard. In 1900 "several hundred" goats were reported on Ile Picard; by 1906 goats had been introduced to Grande Terre where "hundreds" were reported in 1916 and "thousands" in 1929 (Stoddart 1981). During the Royal Society Expedition in 1967-68, goats were observed on all 4 major islands of the atoll and 1 islet in the lagoon -- Ile Picard, Ile Polymnie, Ile Malabar, Grande Terre, and Ile Espirit, respectively (Stoddart 1971).

The first feral goat population census occurred in 1976-77 when 500-600 individuals were estimated atoll-wide (Gould and Swingland 1980). Goats were again censused in 1982 (Newing et al. 1984) and 1985-86 (Burke 1988a) which resulted in population estimates of  $2,560 \pm 560$  and approximately 1,000, respectively. This 2- to 5-fold increase in the goat population in less than a decade prompted greater concern about the impacts feral goats were having on the Aldabra ecosystem. In November

1986 the Seychelles Islands Foundation (SIF) declared that eradication of feral goats by shooting would be the official management policy on Aldabra (Burke 1988b).

UNESCO funded a limited control program in January-March 1987 and 1988 to assess the need and potential for eradicating feral goats from Aldabra. This control program concentrated on the goat population on Ile Malabar and the areas of highest goat concentrations on Grande Terre which resulted in the removal of 883 goats -- 61 from Ile Malabar, 8 on Ile Picard, and 814 from Grande Terre (Coblentz et al. 1990). Goats were altering species composition and regeneration of vegetation, as well as reducing forage and shade cover for the giant tortoise and possibly reducing the habitat of the brush warbler (Coblentz and Van Vuren 1987). Coblentz et al. (1990) recommended the eradication of the remaining goats on Aldabra.

Eradication was recommended because of the danger that limited control would promote increased fecundity and perhaps compromise a control program. Feral goats have a gestation period of 150 days and both sexes can reach sexual maturity before the end of their first year (Rudge and Clark 1978), multiple births are common (Rudge 1969, Coblentz 1982), and females are capable of giving birth at all times of the year (Coblentz 1980, Ohashi and Schemnitz 1987). These traits allow feral goats to respond to reductions in populations with increased reproductive rates (Rudge and Clark 1978, Coblentz 1982, Parkes 1984); a goat population reduced by 80% could rebound to 90% of the original level in only 4 years (Rudge and Smit 1970). Thus, as a component of any control campaign, it is important to understand the population dynamics of the target organism. A knowledge of the likely recovery rate of controlled populations can assist in planning control operations, particularly when reliable methods of assessing abundance are lacking (Rudge and Smit 1970). My objective was to determine if goat productivity on Aldabra responded to population reduction.

## METHODS

### Study Area

Aldabra Atoll (Figure 1.1) is located in the western Indian Ocean approximately 390 km northwest of Madagascar and 650 km east of the African mainland. Aldabra has a total land area of 155 km<sup>2</sup> and consists of four principal islands--Ile Picard (9.3 km<sup>2</sup>), Ile Polymnie (1.8 km<sup>2</sup>), Ile Malabar (26.4 km<sup>2</sup>), and Grande Terre (110 km<sup>2</sup>). The Atoll is approximately 34 km long, and 14.5 km at the broadest section of its north-south axis. The four islands, averaging 2 km in width, are separated by channels and encircle a large (210 km<sup>2</sup>), shallow tidal lagoon.

The climate of Aldabra is semi-arid and tropical (Farrow 1971). Aldabra experiences two seasons: a "wet" season occurring roughly between December and April when lighter and more variable northwesterly monsoon winds bring higher temperatures and the majority of the annual rainfall; and a "dry" season occurring between May and November with lower temperatures and a strong constant southeastern trade wind. The mean average rainfall is 1089 mm, ranging between 547 mm and 1467 mm (Stoddart 1983). The annual range of mean monthly temperatures (24.9°C - 28.4°C) is less than the mean daily minimum and maximum fluctuations (22.2°C - 31.2°C) (Stoddart and Mole 1977).

Aldabra is one of the largest raised coral atolls in the world with an elevation generally between 4 to 8 m above sea level (Stoddart et al. 1971). Soils on Aldabra are generally shallow (10-20 cm), and bare rock often comprises 50% of any given area (Trudgill 1979). The surface morphology can be generally distinguished, albeit oversimply, between two types of limestone: champignon and platin. Most of Aldabra consists of champignon which is characterized by irregular, deeply pitted, and sometimes very jagged surfaces. Platin limestone covers approximately 28% of Aldabra (Stoddart et al. 1971) and occurs mainly on Ile Picard and the eastern part of Grande Terre. Platin is relatively smooth pavement-like limestone that contributes to greater soil formation and is capable of supporting a variety of vegetation.

The vegetation of Aldabra is largely determined by the surface morphology (Fosberg 1971). Four general vegetation zones can be characterized on Aldabra: mangroves, Pemphis scrub, mixed scrub, and coastal grassland. Mangroves border the lagoon and cover almost 20% of the land area (Stoddart and Fosberg 1984). Pemphis scrub grows in the champignon substrate and covers about one-half the land area of Aldabra (Gibson and Phillipson 1983). This scrub is dominated by Pemphis acidula -- a microphyllous evergreen shrub that grows densely to heights of 6 m. Much of the plain area of eastern Grande Terre consists of a more open mixed scrub and woodland community which varies in density, height, and species composition representing a number of taxa (Fosberg 1971, Hnatiuk and Merton 1979). The coastal grassland area is found along the south and east coast of Grande Terre although occasional patches can be found inland. This grassland is dominated by Sclerodactylon macrostachyum which grows in tussocks from 5 - 50 cm in height depending on grazing pressure, and Sporobolus virginicus which grows to 10-20 cm in height (Hnatiuk and Merton 1979).

### Study Design

From October 1993 - May 1994 and November 1994 - May 1995, feral goats were killed on Aldabra Atoll by 2 shooters using .223 caliber rifles. At the outset of the campaign, a large feral goat population was present on Grande Terre, with remnant goat populations existing on Ile Picard and Ile Malabar. Age, sex, physiological condition, and reproductive condition of 793 feral goats; and sex and rump-crown measurements of 205 fetuses, were determined during control efforts on Grande Terre, Aldabra Atoll, from January 1994 - April 1994 and November 1994 - May 1995. Based on logistical and physiographical differences, I divided Grande Terre at Pt. Lion into 2 areas -- West Grande Terre (WGT) and East Grande Terre (EGT). WGT is relatively narrow with open areas concentrated along the coast, and is mostly composed of champignon and dominated by Pemphis scrub. EGT is characterized by plain and mixed scrub with open and semi-open areas throughout.

Pre- and post-natal sex ratios were compared separately to a theoretical 1:1 sex ratio with a chi-square test of fit; post-natal sex ratios were compared within age groups with a 2 x 4 contingency table (Zar 1984). Age was determined by tooth eruption and replacement (Silver 1963); goats were classified as one of the following age categories: birth to 0.5 year, > 0.5 - 1.0 year; > 1.0 - 2.0 years; and > 2.0 years.

Physiological condition was determined based on a subjective 4-point scale kidney fat index (KFI): 1 = no fat around kidneys (poor condition); 2 = small deposits of fat partially covering the kidneys (fair condition); 3 = large deposits of fat partially covering the kidneys (good condition); and 4 = kidneys entirely surrounded by fat (excellent condition). No statistical analysis of KFI data was performed.

Female reproductive condition was classified as non-reproductive, pregnant only, lactating only, or pregnant and lactating. Only females > 0.5 yr were included in the analysis, although all females were examined for lactation and pregnancy. To determine breeding dates, rump-crown measurements of fetuses were used to determine the age of the fetus (Parkes 1984) and then back-dating from the time the mother was killed based on a 150-day gestation period (Asdell 1964). Rump-crown measurements were to the nearest 0.5 cm. When twins were present and of different lengths, the largest fetus was used to determine the age and hence the conception date for both fetuses. If no embryo was identified (< 1 cm), the number of corpora lutea were recorded if present. Each field season was divided into 10-day periods and a chi-square test was used to determine breeding periods during the first and second field seasons.

Reproductive rates were determined based on the number of young produced divided by the number of females excluding those lactating only or < 0.5 years. Number of young included the number fetuses or corpora lutea (when fetuses were not detectable). Goats that were both lactating and pregnant were assumed to have bred twice within the same year. To calculate the intrinsic rate of increase ( $r$ ), a mortality rate of 0.15 was assumed based on mortality rates of 0.10 - 0.19 of other studies (Williams and Rudge 1969, Rudge and Smit 1970, Gould 1979). The natural mortality rate is extremely difficult to determine on Aldabra due to topography and the large number of scavengers. A chi-square test was used to compare the number of multiple

births between seasons. T-tests were used to compare reproductive rates between EGT and WGT, and between the first and second seasons.

## RESULTS

Based on the number ( $n = 793$ ) of feral goats killed by shooting on Grande Terre, the minimum population density was 7.2 goats/km<sup>2</sup>. However, goats were not evenly distributed throughout the island (Figure 1.2). If Grande Terre is divided into western (WGT) and eastern (EGT) halves near Pt. Lion, goat densities were 3.6 goats/km<sup>2</sup> and 12.1 goats/km<sup>2</sup>, respectively. Densities of remnant goat populations on Ile Picard ( $n = 13$ ) and Ile Malabar ( $n = 22$ ) were 0.8 goats/km<sup>2</sup> and 1.4 goats/km<sup>2</sup>, respectively.

The pre-natal sex ratio on Grande Terre (130.8 M:100 F,  $n = 180$ ) was not statistically different from parity ( $\chi^2 = 3.20$ ,  $P < 0.05$ ), although males outnumbered females. Pre-natal sex ratios of single ( $n = 112$ ) and twin fetuses ( $n = 68$ ) were also not significantly different from parity ( $\chi^2 = 2.28$  and  $0.94$ ,  $P < 0.05$ ). The post-natal sex ratio on Grande Terre (90.6 M:100 F,  $n = 793$ ) was not significantly different from parity ( $\chi^2 = 1.94$ ,  $P < 0.05$ ), although females outnumbered males. There were no differences from parity in sex ratios between age classes ( $\chi^2 = 2.51$ ,  $P < 0.05$ ) or between EGT and WGT ( $\chi^2 = 0.32$  and  $1.66$ ,  $P < 0.05$ ).

The age distribution on Grande Terre was almost even between goats  $< 2.0$  years and  $> 2.0$  years, with 46.8% of the males and 52.1% of the females in the  $> 2.0$  year age class (Table 2.1). Twenty-one female goats aged at 5 - 6 months were pregnant with fetuses determined to be too old for the goat to have been in a reproductive condition at the estimated time of conception; these goats likely were older than 0.5 years.

The mean KFI of all male goats ( $n = 284$ ) on Grande Terre was 1.96 (SD = 0.69); mean KFI for all female goats ( $n = 401$ ) was 2.10 (SD = 0.76). Mean KFI was similar between EGT and WGT, and between the first and second seasons for both males and females. Mean KFI based on ages in males differed only slightly between

Table 2.1 Sex and ages of 773 feral goats killed on Grande Terre, Aldabra Atoll between 12 January 1994 - 27 April 1994 and 24 November 1994 - 23 April 1995. Does not include 14 goats of undetermined age (4 ♂ : 10 ♀).

|              | <b>n</b>   | <b>0-0.5 yr</b><br>♂ : ♀ | <b>0.5-1.0 yr</b><br>♂ : ♀ | <b>1.0-2.0 yrs</b><br>♂ : ♀ | <b>&gt; 2.0 yrs</b><br>♂ : ♀ | <b>Total</b><br>♂ : ♀ |
|--------------|------------|--------------------------|----------------------------|-----------------------------|------------------------------|-----------------------|
| E.G.T.       | 533        | 61:59                    | 29:30                      | 37:38                       | 133:146                      | 260:273               |
| W.G.T.       | 240        | 32:27                    | 19:18                      | 19:21                       | 40:64                        | 110:130               |
| <b>Total</b> | <b>773</b> | <b>93:86</b>             | <b>48:48</b>               | <b>56:59</b>                | <b>173:210</b>               | <b>370:403</b>        |



younger and older animals with a mean KFI of 1.77 (SD = 0.56) for males < 2.0 years and 2.23 (SD = 0.73) for males > 2.0 years. Females had a similar mean KFI in both young and old animals, but differed slightly depending on reproductive condition. Females that were only pregnant ( $\bar{x}$  = 2.36; SD = 0.81) or were non-reproductive ( $\bar{x}$  = 2.15; SD = 0.84) had a higher mean KFI than females that were pregnant and lactating ( $\bar{x}$  = 2.03; SD = 0.75) or that were lactating only ( $\bar{x}$  = 1.79; SD = 0.58). The mean KFI for all goats in the remnant populations on Ile Picard and Ile Malabar was 2.53 (SD = 0.78) and 2.08 (SD = 0.72), respectively. The mode KFI for all groups was 2.0.

For all female goats > 0.5 years in the first and second seasons, respectively, 91% (n = 171) and 86% (n = 111) were either pregnant, lactating, or pregnant and lactating (Table 2.2). Of the 17 and 18 goats that were non-reproductive for the first and second seasons, respectively, 47% and 72% were goats > 2 years of age. Females that were pregnant or lactating during the first season comprised 48% (n = 91) and 18% (n = 34) of the population, respectively; 24% (n = 46) were simultaneously lactating and pregnant. During the second season, females that were pregnant or lactating each comprised 36% (n = 46 and 47, respectively) of the population; 14% (n = 18) were both lactating and pregnant.

Natality for the first season was 1.43 kids/female/season; for the second season, natality was 1.25 kids/female/season. For the first season, using a birth rate (b) of 0.71 female kids/female/season and the annual survival rate of 0.85 and mortality rate (d) = 0.15, the intrinsic rate of increase (r) is  $b - d = 0.45$ ; for the second season,  $r = 0.39$ . Twinning rates were 30.7% and 37.5% in the first and second seasons, respectively. The twinning rates did not differ significantly between seasons ( $\chi^2 = 1.62$ ,  $P < 0.05$ ). In the lower goat density area of WGT, twinning rates were 44.2% and 50.0% in the first and second season, respectively; in EGT twinning rates were 21.3% and 32.6% in the first and second season, respectively. No triplet fetuses were ever observed on Grande Terre, but 3 sets of triplet corpora lutea were observed; 1 female had triplet fetuses on Ile Picard. Females > 2.0 years were responsible for a greater proportion of multiple births with 69% and 79% of all multiple births in the first and second season,

Table 2.2 Number and percentages ( ) of categories of reproductive condition of female goats > 0.5 yr of age killed on Grande Terre, Aldabra Atoll, between 12 January 1994 - 27 April 1994 and 24 November 1994 - 23 April 1995.

|                         | First Season |              |                      | Second Season |              |                      |
|-------------------------|--------------|--------------|----------------------|---------------|--------------|----------------------|
|                         | E.G.T.       | W.G.T.       | TOTAL                | E.G.T.        | W.G.T.       | TOTAL                |
| Total ♀<br>(> 0.5 yr)   | 126          | 62           | <b>188</b>           | 88            | 41           | <b>129</b>           |
| Pregnant<br>Only        | 68<br>(0.54) | 23<br>(0.37) | <b>91<br/>(0.48)</b> | 36<br>(0.41)  | 10<br>(0.24) | <b>46<br/>(0.36)</b> |
| Lactating<br>Only       | 21<br>(0.17) | 13<br>(0.21) | <b>34<br/>(0.18)</b> | 33<br>(0.38)  | 14<br>(0.34) | <b>47<br/>(0.36)</b> |
| Pregnant &<br>Lactating | 26<br>(0.21) | 20<br>(0.32) | <b>46<br/>(0.24)</b> | 10<br>(0.11)  | 8<br>(0.20)  | <b>18<br/>(0.14)</b> |
| Non-<br>Reproductive    | 11<br>(0.09) | 6<br>(0.10)  | <b>17<br/>(0.09)</b> | 9<br>(0.10)   | 9<br>(0.22)  | <b>18<br/>(0.14)</b> |

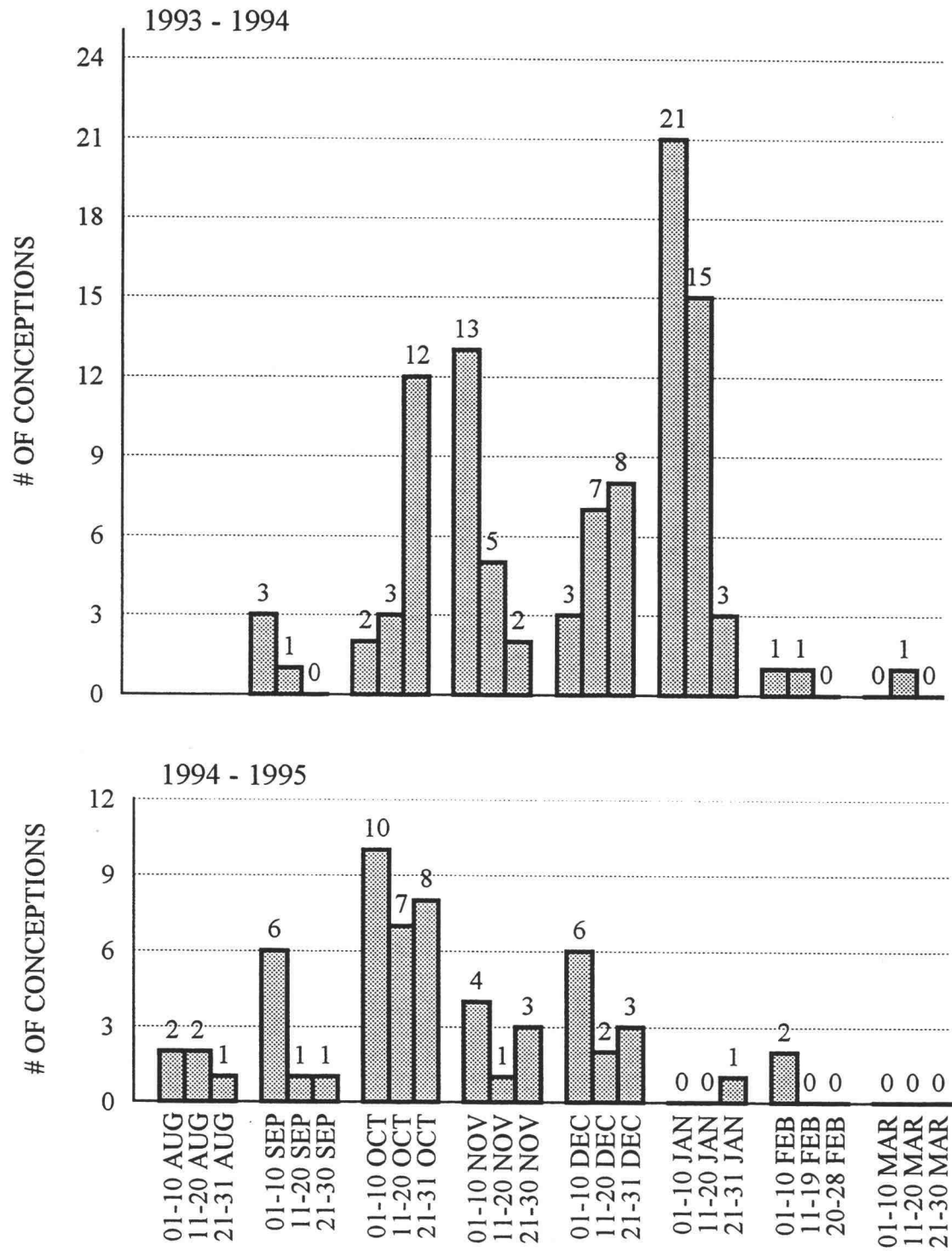


Figure 2.1 Conception dates for pregnant goats during the first (Jan - Apr 1994) and second seasons (Dec 1994 - May 1995) on Grande Terre, Aldabra Atoll based on back-dating rump-crown measurements of fetuses.

respectively. Feral goats on Grande Terre exhibited a bimodal breeding pattern between 20 October - 10 November and 21 December - 20 January during the first season (Figure 2.1); a single peak was observed 01 October - 31 October during the second season (Figure 2.1). The months of April through August and April through July are not represented in this analysis for the first and second seasons, respectively.

## DISCUSSION

Feral goats on Aldabra may be unique among feral goat populations by apparently not responding to population reductions in a density-dependent manner and remaining essentially the same in both the first and second seasons. Nor do Aldabra goats appear to achieve the reproductive potential of domestic goats or other insular populations as evidenced by their low densities and uneven distributions. Reasons for this may be the harsh environmental conditions on Aldabra, notably lack of freshwater, and low forage productivity or palatability.

Goat densities on Aldabra were lower than other insular feral goat populations. Based on the total number of goats killed ( $n = 798$ ) on Grande Terre ( $110 \text{ km}^2$ ) during this project, the goat density was  $7.2 \text{ goats/km}^2$ ; adding the estimated maximum of 120 goats remaining on the atoll would result in a population density of approximately  $8.3 \text{ goats/km}^2$ . Past population estimates on Grande Terre have also been low ( $2.0 - 3.7 \text{ goats/km}^2$  in 1977 and  $5.9 - 10.4 \text{ goats/km}^2$  in 1985, Burke 1988a). In 1977, Ile Malabar had the greatest density of goats on Aldabra with approximately  $17 \text{ goats/km}^2$  (Gould and Swingland 1980). During goat control activities in 1987-88, goat densities based on goats killed ( $n = 777$ ) on Grande Terre was  $7.1 \text{ goats/km}^2$  (Coblentz et al. 1990), however, many more goats remained so this must be viewed as a conservative estimate. Densities of other insular feral goat populations have been  $16-22 \text{ goats/km}^2$  on Saturna Island (Shank 1972);  $23 \text{ goats/km}^2$  in Haleakala National Park, Hawaii (Yocum 1967);  $27.5 \text{ goats/km}^2$  on Aguijan, Marianas Islands (Rice 1991);  $26-41 \text{ goats/km}^2$  on Santa Catalina Island, California (Coblentz 1977);  $27.9-72.5 \text{ goats/km}^2$  on Raoul Island, New Zealand (Rudge and Clark 1978);  $137 \text{ goats/km}^2$  on

James Island (Calvopina 1985) and 339-678 goats/km<sup>2</sup> on Pinta Island, Gálapagos (MacFarland et al. 1974); and 1,000 goats/km<sup>2</sup> on Macauley Island, New Zealand (Williams and Rudge 1969).

Goats were not evenly distributed on Grande Terre. Densities of WGT and EGT were 3.6 goats/km<sup>2</sup> and 12.1 goats/km<sup>2</sup>, respectively. The greatest goat densities occurred in the Cinq Cases area of southeast Grande Terre where 152 goats were killed in an area of approximately 5.5 km<sup>2</sup> (27.6 goats/km<sup>2</sup>). The density of goats in an area of 17 km<sup>2</sup> was 7.5 - 13.0 and 28.2 - 49.4 goats/km<sup>2</sup> in 1977 and 1985, respectively (Burke 1988a). During goat control activities in 1987, 292 goats were killed in an approximately 3.0 km<sup>2</sup> area (97.3 goats/km<sup>2</sup>) between the lagoon and Cinq Cases (Coblentz et al. 1990). This area of Grande Terre is the most open, and has the greatest variety of vegetation. Goat distribution on Ile Malabar was also restricted with goats occurring on the eastern end of the island from Middle Camp to slightly west of Anse Grande Grabeau. This area, too, is open with the greatest variety of vegetation. Goat densities may be limited on Aldabra due to the lack of open or semi-open habitat where they tend to concentrate, and the lack of non-Pemphis vegetation.

The incidence of twinning is widely reported in feral goats, but is low on Aldabra compared to other insular populations. During this project, twinning frequency on Grande Terre was 30.7 and 37.5% in the first and second seasons, respectively. No triplet fetuses were observed on Grande Terre, although 3 triplet corpora lutea were observed; 1 set of triplet fetuses was recorded on Ile Picard. In-utero twinning frequency in other studies was 52% on North Island (Rudge 1969); 30.5% on Macauley Island (Williams and Rudge 1969); and 50.9% on San Clemente Island where 9.8 % of all pregnancies were triplets (Keegan et al. 1984b). On Aldabra, the frequency of live twinning was also low with 21% in 1976-77 and 6% in 1985-86 in the Cinq Cases region of Grande Terre; 18% in the Dune Jean Louis region in 1976-77; and no sightings in 1976-77 to 20% in 1985-86 on Ile Malabar (Burke 1988a). Twinning rates based on observed kids have been reported at 50% in Hawaii (Yocum 1967); 25% in New Zealand (Rudge 1969); and 11.1 to 80.0% on Santa Catalina Island, California (Coblentz 1982).

Reproductive rates did not increase between the first and second seasons in response to a drastic reduction in the population as in other feral goat populations (Rudge and Smit 1970, Baker and Reeser 1972, Coblentz 1982, Parkes 1984). Natality on Aldabra was 1.43 kids/female/season during the first season, and 1.25 kids/female/season during the second season; the intrinsic rate of increase for the first and second seasons was 0.45 and 0.39, respectively. Although methodology may be slightly different, these rates are comparable to other insular populations. On Ile Malabar in 1976-1977, Gould (1979) found the annual fecundity was 0.386 female offspring/female/year (Gould 1979). On Raoul Island, fecundity increased from 0.96 kids/female/year in 1972 to an average of 1.70 kids/female/year in 1983 (Parkes 1984). Annual recruitment on Macauley Island was 1.7 kids/female/year (Williams and Rudge 1969). Rudge and Clark (1978) estimated 0.83 - 0.94 kids/female/year on Raoul Island. On North Island, New Zealand, an average of 0.950 kids/female/year was determined (Rudge 1969).

For all female goats > 0.5 years in the first and second seasons, respectively, 91% (n = 171) and 86% (n = 111) were either pregnant, lactating, or pregnant and lactating (Table 2.2). The 9% and 14% non-reproductive females in the first and second seasons, respectively, are comparable to the range of 7.7 - 33% non-reproductive females reported in other studies (Rudge 1969, Williams and Rudge 1969, Coblentz 1982, Keegan et al. 1994b). Females that were simultaneously lactating and pregnant, 24% in the first season and 14% during the second, and assumed to have given birth twice within the same year, was also comparable to the 9 - 20% reported in other studies (Rudge 1969, Williams and Rudge 1969, Coblentz 1982, Keegan et al. 1994b).

Unlike other studies, young goats on Aldabra were likely to be pregnant. Of the 17 and 18 goats that were non-reproductive for the first and second seasons, respectively, 47 % and 72 % were > 2 years of age. On Macauley Island, pregnancy rate varied with age of females; fewer females were in non-breeding condition in the > 2 year class (4.0%) than in the 1-2 year class (27%), and simultaneous pregnancy and lactation was almost entirely confined to the older females (Williams and Rudge 1969).

Gould (1979) estimated that goats first bred on Aldabra at ages 14-17 months, but it is probable that many are breeding before 12 months of age. Although aging goats is somewhat inaccurate due to delayed tooth loss and replacement on Aldabra compared to that of domestic goats (Silver 1963), 21 females aged at 5 - 6 months were pregnant. Conception in domestic goats can occur at 6 months of age (Asdell 1964) and pregnant goats < 12 months of age have been recorded in other field studies on Saturna Island (Geist 1960), Haleakala National Park (Yocum 1967), North Island (Rudge 1969), and Raoul Island (Rudge and Clark 1978).

Considering that reproductive rates are comparable to other insular goat populations, there must be other factors involved causing the low density and lack of reproductive response to control measures. On Macauley Island, a death rate between 34 - 57 % was reported for goats between birth and 0.5 year which may have been caused by dry conditions and imposed severe stresses on nursing females (Williams and Rudge 1969). Obviously finding dead goats due to natural causes would be fairly conclusive evidence of harsh conditions, but carcasses on Aldabra were rarely found due to the topography, and the large number of scavengers such as giant tortoises, sacred ibis (*Threskiornis aethiopica abbotti*), and land crabs (e.g., *Birgus latro* and *Cardisoma carnifex*) which removed practically all traces of carcasses in a matter of days. The only carcasses we found on Grande Terre that died of natural causes were 3 Judas goats, and a single female which was in the bottom of a champignon sinkhole. Gould (1979) found evidence of only 17 natural mortalities atoll-wide during 16 months. Burke (1988b) estimated the average life expectancy of Aldabra feral goats at 4 to 5 years with a maximum of 8 years. This is similar to New Zealand, where the oldest goats shot were 6 years old according to tooth wear patterns (Rudge 1969). During this project, very few goats on Aldabra were obviously old individuals.

Burke (1987) suggested a mating system based on no dominance hierarchy with extreme physical harassment of females by males to explain a perceived male-biased sex ratio and low reproductive success. However, this hypothesis does not appear to be valid; the sex ratio in this study was actually female-biased (370 M:403 F) as was that

determined by Coblenz (unpublished data) in 1988 (256 M: 273 F). I also found the sex ratio of all prenatal goats on Aldabra to not be different from parity (102 M: 78 F).

Probably the most important factors affecting the feral goat population on Aldabra are climatic conditions and rainfall. The mean annual rainfall is only 1,089 mm (Stoddart 1983), and is concentrated during the monsoon season, which usually lasts for 5 months, but may occasionally be as short as 2 months; strong winds and clear skies cause rapid evaporation of any rainfall during the remainder of the year (Farrow 1971). The porous champignon limestone which constitutes most of Aldabra, does not allow water to collect and rain puddles do not last more than a few days. The relatively impermeable platin limestone in much of EGT is the only place where permanent or semipermanent water sources may form on Grande Terre. During the dry season, goats must obtain their water requirements from their diet, although goats have been observed to drink saltwater from ocean tidal pools and the lagoon (Burke 1990).

Rainfall profoundly affects forage. Previous studies on Aldabra suggest that water availability and diet quality influenced the reproductive rates of goats (Burke 1988a). Some plant species lose their leaves during the dry season, and all showed flushes of new growth with the onset of rain (Burke 1988a, pers. obs.). Vegetation became less nutritious and digestible with age and dryness, as determined by DAPA levels (the level of 2,6-diaminopimelic acid in the feces) to assess diet quality (Burke 1988a). In 1985, the goat population at Dune d'Messe had the highest DAPA levels and thus the best diet quality, and also had the largest body sizes and only observed incident of triplet fetuses. The Cinq Cases population had the lowest DAPA levels and poorest diet quality in 1985, and also had the smallest body size, lowest percentage of reproductive females, and the lowest twinning frequency (Burke 1988b).

Most goats on Aldabra had only small deposits of perirenal fat. The lack of fat reserves may be due to the seasonal lack of forage and fresh water. On San Clemente Island, California, where goat densities were also very low, mean KFI as determined by the same 4-point scale was 3.3 (SD = 0.9) (Keegan et al. 1994b). Likewise, mean KFI for the remnant goat population on Ile Malabar where presumably more forage would be available due to the low number of goats was 2.53. However, the mean KFI on Ile



Picard where the same conditions would exist was 2.08 which is similar to the values on Grande Terre.

Low reproductive rates and high mortality have been linked with environmental conditions and forage quality in other studies. Dry conditions imposed severe stresses on lactating females and may have been the main cause of the 34 - 57 % death rate of goats between birth and 0.5 year on Macauley Island (Williams and Rudge 1969). On Santa Catalina Island, California, higher pregnancy rates and juvenile survival occurred in months during or immediately following peak production of annual vegetation (Coblentz 1982). Also on Santa Catalina, the difference in twinning rates (11.1 to 80.0%) was considered dependent, at least in part, upon the quality and quantity of forage available to females (Coblentz 1982). Poor forage conditions and stressful environmental conditions have also caused lowered reproductive rates in populations of other ungulate species (Teer et al. 1965, Sinclair 1977, Dunbar 1990).

Feral goats on Grande Terre exhibited a bimodal breeding pattern between 20 October - 10 November and 21 December - 20 January during the first season; a single peak was observed 01 October - 31 October during the second season. The months of April through August and April through July are not represented in this analysis for the first and second seasons, respectively. The corresponding birthing peaks would be 21 March - 10 April and 21 May - 20 June for the first season; 01 March - 30 March for the second season. In 1976-77 on Ile Malabar, Gould (1979) observed breeding throughout the year but with a major breeding peak in January-March (birth peak June-August) and a minor breeding peak in May-July (birth peak October-December). Gould (1979) argued the rains normally beginning in November, and the breeding peak in January-March, would allow females a few to several months to increase energy reserves during the time of minimal reproductive costs and maximal nutritional benefits. However, the periods of maximum energy demand for a female would be in the early to mid-dry season during late pregnancy and early lactation when water sources are decreasing. The onset of the breeding season on Aldabra may be the result of rainfall and the resulting flourish of new vegetation.

## MANAGEMENT IMPLICATIONS

Despite feral goats on Aldabra not reaching densities comparable to other insular populations, the threat to the biota of Aldabra is still significant. Although original concern was expressed about the potential impact of feral goats on the habitat of the Aldabran brush warbler (Nesillas aldabranus) on Ile Malabar (Prys-Jones 1978, Gould and Swingland 1980), the greatest threat of feral goats to the Aldabra ecosystem may be their direct and indirect impacts on the vegetation and giant tortoises. The high densities of goats in the southeastern region of Grande Terre between Cinq Cases and Anse Takamaka is ecologically important due to the high numbers of both giant tortoises (Bourn and Coe 1978) and the variety of indigenous vegetation in this same region (Gibson and Phillipson 1983).

Feral goats are considered to compete with giant tortoises (Geochelone elephantopus and G. gigantea) on both the Galapagos (MacFarland et al. 1974) and on Aldabra (Coblentz and Van Vuren 1987). With a population of approximately 150,000 (Bourn & Coe 1978), the greatest densities of tortoises occur in the southeastern part of Grande Terre where densities reach a maximum of >100 tortoises/ha in the coastal and mixed scrub during the wet season (Gibson and Hamilton 1983). Feral goats principally affect giant tortoises on Aldabra in two ways: directly by competing for food and indirectly by reducing the availability of shade through browsing.

Although no quantitative data were collected during this project regarding the impact of feral goats, observations were made. The most obvious impact of feral goats was the 1.5 - 2.0 m browse lines occurring on much of the vegetation along the coastal areas of Grande Terre, as well as the lack of seedling regeneration and resprouting of new vegetation below the browselines. Browselines were also observed by Gould (1979), Coblentz and Van Vuren (1987), and Scoones et al. (1989). With tortoises creating a browse line of 0.6 m (Merton et al. 1976), feral goats are obviously removing food resources above and out of reach of the tortoises, thus competing directly with tortoises to some degree. The impact of browsing was particularly evident on isolated clumps of vegetation near the coast which provided tortoises their only refuge from the

sun. All tortoises seek shade during midday (Swingland and Lessells 1979), and the southeastern region of Grande Terre is the most open area of the atoll where shade is especially limited. Heat stress is the major mortality factor of giant tortoises on Aldabra and increases as the animals must graze further from shade (Swingland and Lessells 1979; Swingland and Frazier 1980; Gibson and Hamilton 1983). Tortoise mortality is more evident in this area than anywhere else on the atoll with both bleached carapaces and recently dead tortoises found. No recently dead tortoises, and very few skeletal remains were found elsewhere on the atoll.

Tortoises in southeastern Grande Terre were observed to be much smaller than anywhere else on the atoll, as well as the only individuals observed to readily consume meat. Tortoises were one of the most common scavengers of goat carcasses, as well as any other dead animals. Tortoises on Ile Malabar and Ile Picard were never observed feeding on goat carcasses. These observations may be a result of nutritional deficiencies and competition with feral goats. At the conclusion of this project when virtually all goats were eliminated from this region, basal sprouting was occurring below the 2 m browseline on Pemphis and Guettarda shrubs.

These observations support the conclusion that goats are detrimental to the ecosystem on Aldabra, the recognition of the biological values of Aldabra as a World Heritage Site, and the policy that goats should be eradicated. Low goat densities and seeming lack of reproductive response to control should not be viewed as a lack of need for control, or requiring only sporadic control efforts, but should be seen as an opportunity to achieve eradication.

## Chapter 4 SUMMARY

Feral goats (*Capra hircus*) have seriously affected native vegetation (Furon 1958, Mueller-Dombois and Spatz 1974, Coblenz 1977, Hamann 1979, Cronk 1986) and wildlife (MacFarland et al. 1974, Franklin et al. 1979, Leathwick et al. 1983, Cruz and Cruz 1987) in numerous areas of the world. The greatest threat of feral goats to the Aldabra ecosystem may be their direct and indirect impacts on the vegetation and giant tortoises. Feral herbivorous mammals are so destructive that it is virtually impossible to preserve or restore an island ecosystem without their elimination (Vitousek 1988).

Although traditional hunting is an efficient control method when goat densities are high, Judas goat hunting is an efficient control method for remnant goat populations as evidenced by the eradication of goats on Ile Picard and Ile Malabar, as well as Hawaii Volcanoes National Park (Taylor and Katahira 1988) and San Clemente Island (Keegan et al. 1994a). Traditional hunting is an efficient means to control goats during the initial phase of a control program, but Judas goats allow eradication to be realized in an efficient and timely manner.

From October 1993-May 1994 and November 1994 - May 1995, a total of 832 goats were killed on Aldabra using both the Judas goat technique and traditional hunting methods. The remnant goat populations on Ile Picard (N = 13) and Ile Malabar (N = 19) were eradicated during the first season, and a total of 798 (374 M: 424 F) goats were killed on Grande Terre. The overall kill rate on Grande Terre was 0.37 goats killed/hour with 1.66 shots fired/goat. A total of 1,042 goats were encountered of which 26.1 % escaped. Mean group size was 3.2 with a range of 1 to 20. A total of 28 Judas goats were utilized during the entire campaign. Judas goat hunting became increasingly important over time with 18.0% (n = 85) of goats killed in the first season in the presence of Judas goats; 42.3% (n = 126) of goats killed during the second season were in the presence of Judas goats. The overall kill rate for the project was almost 2 times greater for Judas goat hunting (0.61 goats killed/hr) than

traditional hunting (0.32 goats killed/hr), and Judas goat hunting was approximately 70% more effective than traditional hunting when compared using multiple linear regression. There was a significant relationship between Judas goat home range size and the number of conspecifics killed. Feral goats on Aldabra may be unique among feral goat populations by apparently not responding to population reductions in a density-dependent manner. For the first season, the intrinsic rate of increase ( $r$ ) was 0.45;  $r = 0.39$  for the second season. Twinning rates were 30.7% and 37.5% in the first and second seasons, respectively. Low goat densities of approximately 7.2 goats/km<sup>2</sup> and apparent lack of reproductive response to control should not be interpreted as a lack of need for control, or requiring only sporadic control efforts, but should be seen as an opportunity to achieve eradication.

For any control campaign, there must be (1) a plan including an initial reconnaissance and monitoring period to familiarize control personnel with the area and determine the extent of the target population, (2) uninterrupted implementation of the control plan, (3) a monitoring program to ensure the target organism has been eradicated, and (4) sufficient resources to see the project through to a successful conclusion. The success of any control program does not depend on the number of animals killed, but on the numbers remaining. The Judas goat technique is an effective means of locating goats in low density populations and is a valuable conservation tool that can assist in maintaining the native biota of insular systems still plagued by feral goats.

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